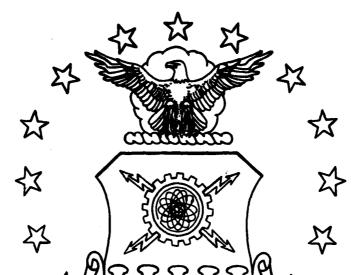
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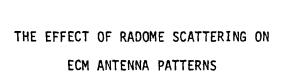
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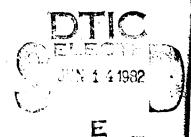
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THESIS

AFIT/GE/EE/81D-52

Robert K. Schneider 2Lt USAF



Prepared as partial fulfillment of the requirements for the Degree of Master of Science

THE EFFECT OF RADOME SCATTERING ON ECM ANTENNA PATTERNS

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

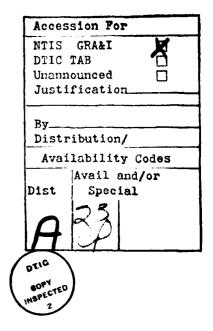
by

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Graduate Electric Engineering

December 1981



Preface

This thesis pertains to a very significant problem, the formation of secondary lobes in antenna radiation patterns due to dielectric radomes. The problem is not understood well enough to even suggest a sure approach to obtaining a solution. This study is only one of several studies which could be made. Yet, it is meant to be a foundation which other studies could be built upon to eventually engineer a definite solution. Several interesting complexities of the problem are realized by this study and are discussed to set that foundation to work from.

The symbols used throughout this paper are the same as those used in the literature sighted or are defined as they occur. The primary reference used was <u>Time-Harmonic Electromagnetic Fields</u> by R. F. Harrington (Ref. 2), and the symbols follow almost without variation from that text.

It should be pointed out that this thesis contains theory on series solution and moment method solution formulations. But, most of the time for this study was spent learning about and working on the Hewlett-Packard 21MX M series minicomputer. This system was chosen to be used because of its easy accessability. A sincere thanks is extended to ASD/ENAMA for the unlimited use of their system as well as for the use of other resources and also to the support from that branch especially through William J. Kent, electronic warfare engineer.

An error was discovered having to do with the results from the series solution presented herein. The theory is correct, but the calculations of the coefficient $\mathbf{F}_{\mathbf{n}}$ is double what it should be for orders not equal to zero. This error should not change the results for the scatterer of six

nate. But, for a diameter of sixty wavelengths the error could become significant and should be checked against the results in Appendix E. The results from the moment method are considered to be correct.

A special thanks goes out to my advisor, Major August Golden, Jr..

He provided the motivation and guidance which was needed throughout this study. And, the scrutinized reading of this thesis by Bill Kent and Captain Thomas Johnson was also sincerely appreciated.

Robert K. Schneider

Dedication

This thesis is dedicated to my wife, Linda, and to my family at home. They all had confidence that the hard work would pay off and were the inspiration I needed.

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Abstract

The problem of scattering by thin cylindrical dielectric shells of large circular cross sections is approached by two methods: (1) an infinite series of eigenfunctions, and (2) the method of moments. Numerical results are presented for shell radii of 0.3λ , 3.0λ , and 30λ , the source being an electric line current near but external to the shell. Computer programs are presented which implement these two solutions. When the scattering structure does become large limitations on numerical results are encountered due to computer memory and speed limitations. Other difficulties are also encountered in an analysis of such scattering problems and are presented and discussed along with recommendations to resolve such difficulties.

I. Introduction

Scattering by perfectly conducting obstacles is exhaustively discussed in the literature (Ref. 1; 2; 3; 4; and 5). The same is not true for scattering by dielectric bodies. Several studies have been done dealing with scattering from planar dielectric surfaces (Ref. 1; 2; 3; 4; 5; 6; and 7). Pathak (Ref. 7) gives an exhaustive analysis of the diffraction of a TM_O. Surface wave by a dielectric slab terminated and flush mounted in a perfectly conducting surface. This thesis is motivated by the study of radomes which are usually curved surfaces. Studies of the scattering by curved dielectric surfaces have been rather limited. Most of the articles found in the literature concentrate on scattering by solid dielectric cylinders of circular or elliptical cross section (Ref. 8; 9; 10; 11; 12). Some studies have been done concerning other curved structures (Ref. 13 to 20).

Kuester and Chang (Ref. 14) investigate the continuous radiation of a wave as it travels along a uniformly curved section of open waveguide. They present a technique for determining the radiation loss at a discontinuity in curvature. A very modest study of the radome scattering problem has been done modeling with a cylindrical shell. Lewin, Chang, and Kuester (Ref. 13:95) examine the case of plane wave incidence on the scattering surface, which lends insight to the problem but is not exactly the case when the source is assumed to be very close to the scattering surface.

Thiele (Ref. 21:306) explains the theory behind the method of moments as do Harrington (Ref. 22) and Richmond (Ref. 23). Harrington and Richmond apply this method directly to scattering from a dielectric. circular cylindrical shell for small geometries; that is, cross sections of less than

 $40/\pi$ wavelengths. Richmond details the technique of setting up the equations to calculate the scattered field and discusses employing the Lagrange Interpolation method (Ref. 24) to reduce the size of the matrix arrived at. Richmond's study only applies to geometrics much smaller than the sixty wavelength cross section (see Appendix A) of concern in this report. Also, Harrington (Ref. 2:198) develops the basics for setting up a series (or eigenfunction) solution for this problem using cylindrical wave functions.

This thesis develops an infinite series of eigenfunctions as a solution for the scattering of electromagnetic waves incident from a nearby electric current filament upon a dielectric, cylindrical shell of circular cross section. A computer program is used to generate numerical results from this series solution. These results are compared to Richmond's (Ref. 23:338) for the geometry indicated there. The solution by the method of moments is also developed and programmed. Results are compared to those from the infinite series solution. The geometry is then enlarged to approach the sixty wavelength cross section of interest. The objective is to compare the results obtained from the infinite series solution and those from the moment method solution, and thus obtain confidence in the solution. Finally, difficulties encountered from either solution method are enumerated and discussed.

II. The Problem and Approach

The radome and antennas configuration to be modeled is shown in Figure 1. The antennas are located six inches behind the radome in the metallic fuselage and have beam maximum at 45° from the skin of the aircraft. The resulting antenna radiation pattern is shown in Figure 2.

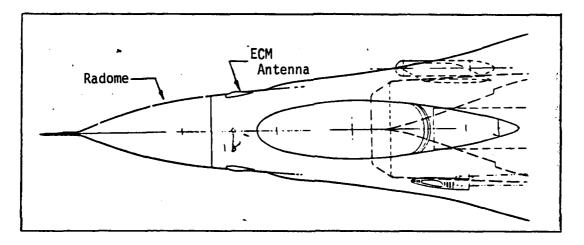


Figure 1. Antenna/Radome configuration.

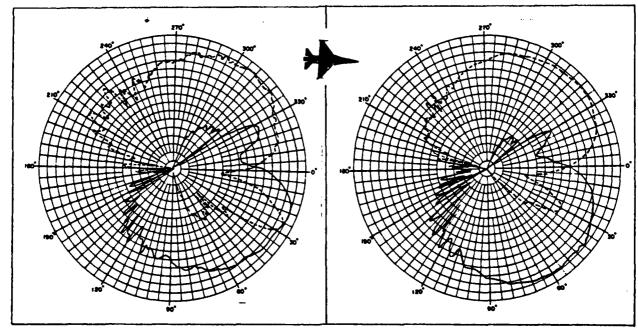


Figure 2. Present radiation pattern.

Figure 3. Recommended radiation pattern.

Note in Figure 2 the secondary lobes at plus and minus thirty degrees, their magnitude being only about 1dB down from the primary lobe. The fact that the patterns overlap off the zero degree line is likely due to asymmetry in product manufacturing and installation of the aircraft antennas and radome. The recommended radiation pattern appears in Figure 3. The secondary lobes have been decreased to about 6dB below the primary lobe and cross over occurs at zero degrees. A comparison of the ideal and typical patterns radiated appears in Figure 4.

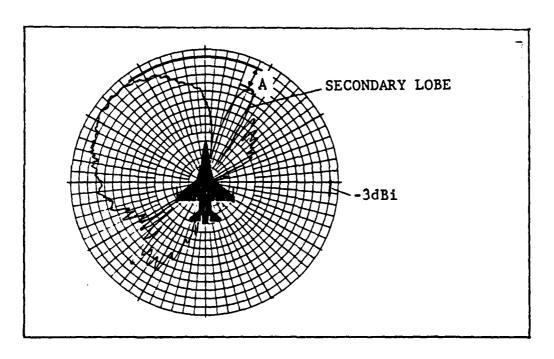


Figure 4. Formation of the secondary lobe from the left-hand antenna relative to the ideal pattern.

The main concern here is the cause of the undesired secondary lobe. This thesis does not answer that question but investigates an approach which might be useful in engineering an answer. As a first step toward that answer, the problem is modeled as shown in Figure 5.

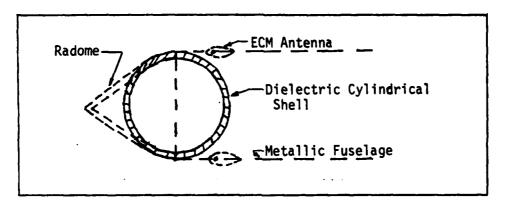


Figure 5. Modeling the radome as a dielectric cylindrical shell and the ECM antennas as line sources.

This model is simply a dielectric, cylindrical shell of circular cross section with an external line source. The model does not account for the metallic fuselage, but it may still lend some insight to how electromagnetic radiation scatters from large, curved structures. In addition, this model and approach may bring out some of the problems which will be encountered in trying to answer the question of lobing due to large structures.

III. The Basic Theory

A. Separation of Variables/Eigenvalue Method

The geometry to be analyzed is shown in Figure 6. It is assumed that the cylindrical shell and the line source are infinite in z and that there is no z-variation in any quantity. All quantities have an $e^{j\omega t}$ time dependence assumed and suppressed. Since the source is a z-directed electric current, the potential due to the source is a vector potential \overline{A} , with

$$A_{z} \neq 0$$
 (F = 0; A_{p} , $A_{\phi} = 0$) (1)

Note that in this study $\overline{H} = \overline{\nabla} \times \overline{A}$ which is consistent with Harrington (Ref.

2). The current on the wire is given by (also see Appendix B)

$$\overline{J} = I \delta(\overline{r}) \hat{Z} \tag{2}$$

It is assumed that the permeability in each region is that of free space. Also, it is assumed that the dielectric material is a perfect insulator, having a zero loss tangent.

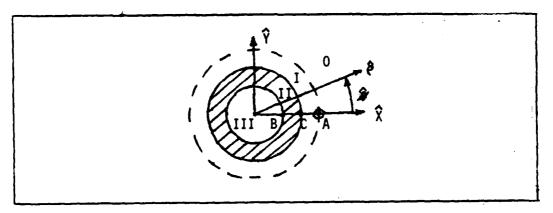


Figure 6: Model for the eigenvalue solution, including the numbered regions.

The fact that there is no variation with z and that there is only a nonzero scalar potential given by (1) implies that A_z must be a solution to the

scalar Helmholts equation for source-free regions (3), where the surfaces in Figure 6 are not in any region but present boundary conditions to those regions.

$$\overline{\nabla}^2 A_z + k^2 A_z = 0 \tag{3}$$

A solution to (3) in cylindrical coordinates is (Ref. 2:199)

$$A_{z} = B_{n}(k_{\rho}\rho) h_{n}(\phi) \tag{4}$$

where

$$\frac{\partial}{\partial z} = 0, k_z = 0 \tag{5}$$

 $B_n(k_\rho\rho)$ is some solution to Bessel's equation of order n and $h_n(\phi)$ is sin ϕ , cos ϕ , or some linear combination thereof. The separation parameter equations are

$$k_{\rho_i}^2 + k_z^2 = k_i^2$$
; i = 0, I, II, III (6)

substituting (5) into (6) yields

$$k_{\rho_i} = k_i; i = 0, I, II, III$$
 (7)

From (1) and (5) the electric field intensity can be written as

$$E_{7} = -\hat{Z}_{0} A_{7} \tag{8}$$

where

$$\hat{Z}_{0} = j\hat{\omega \mu}$$
. The magnetic field is

$$\overline{H} = \frac{\partial A_z}{\partial \rho} \hat{\phi} \frac{1}{\partial} \frac{\partial A_z}{\partial \phi} \hat{\rho}$$
 (9)

For the continuous geometry shown in Figure 6, one would (correctly) expect the potential to have even symmetry about the origin, hence a cosine variation in ϕ .

$$A_{z_i} = B_n(k_i \rho) \cos(n\phi)$$
, n an integer (10)

From (8) and (10) the total field for a given region, i, and azimuthal index,

n, is given by

$$E_{z_{\hat{1},n}} = j_{\omega\mu_0} B_n(k_{\hat{1}}\rho) \cos(n\phi)$$
 (11)

Referring to Table 5.1 (Ref. 2:203), the potentials for the respective regions can be written as follows:

where

$$k_0 = \omega \sqrt{\mu_0 \epsilon_0} = \frac{2\pi f}{C} = \frac{2\pi}{\lambda_0}$$
 (13)

$$k_2 = \omega \sqrt{\nu_0 \varepsilon_0} = \omega \sqrt{\nu_0 \varepsilon_0 \varepsilon_r} = k_0 \sqrt{\varepsilon_r}$$
 (14)

and

 $H_n^{(2)}$ the Hankel function of order n of the second kind J_n is the Bessel function of the first kind N_n is the Neuman function (also called the Bessel function of the second kind)

These potentials automatically satisfy appropriate boundary conditions at the origin and the radiation condition. Equation (16) contains six unknown constants for a given order n, $A_n cdots F_n$. To solve for these six unknowns the following general boundary conditions are applied (see Figure 7):

$$\hat{n} \times (\overline{H}_{i} - \overline{H}_{i+1}) = \overline{J}_{s}$$

$$(\overline{E}_{i} - \overline{E}_{i+1}) \times \hat{n} = \overline{M}_{s}$$
(15)

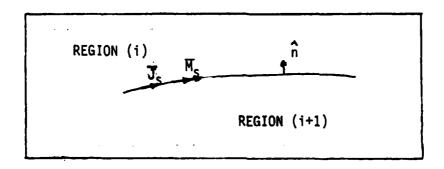


Figure 7. Geometry for the boundary conditions over a surface S.

Since the obstacle (the dielectric, cylindrical shell) is not a magnetic conductor and is assumed to be perfectly insulating, the magnetic and conduction current are neglected. With this the following six boundary conditions result:

$$\hat{n} \times \overline{E}_{i,n} = \hat{n} \times \overline{E}_{(i=1,n)}$$
, $i = 0$, I, II @ $\rho = a$, c, b respectively (a)

$$\hat{n} \times \overline{H}_{t,n} = \hat{n} \times \overline{H}_{(t+1,n)}$$
, $i = I$, II $\emptyset \rho = c$, b respectively (b) (16)

$$n \times \overline{H}_{0,n} - n \times \overline{H}_{1,n} = \overline{J}_{s},$$
 $@ \rho = a$ (c)

where $\overline{J}_S = \frac{I}{a} \, \xi(\phi) \, \hat{z}$ on the ρ = a surface as shown in Appendix B. The goal is to determine the far-zone radiation pattern from the line source in the presence of the obstacle. This field will be given by a sum of the field given by (11) and (12a) over all possible modes.

$$E_{z}(\rho_{0}, \phi_{0}) = J_{\omega\mu} \sum_{n=0}^{\infty} F_{n} H_{n}^{(2)} (k_{0}\rho_{0}) \cos (n\phi.)$$
 (17)

The observation point for the field in the far zone is (ρ_0, ϕ_0) . From (17) it is evident that the only coefficient that need be solved for is F_n . This means that once the problem is solved for F_n for each n from zero to infinity, the radiation at all points in region 0 can be directly obtained.

By applying (16) six_equations in six unknowns result (see Appendix B) which can be arranged into the follow matrix equation:

$$\begin{bmatrix} J_{n}(k_{o}a) & N_{n}(k_{o}a) & 0 & 0 & 0 & -H_{n}^{(2)}(k_{o}a) \\ J_{n}(k_{o}c) & N_{n}(k_{o}c) & -J_{n}(k_{2}c) & -N_{n}(k_{2}c) & 0 & 0 \\ 0 & 0 & J_{n}(k_{2}b) & N_{n}(k_{2}b) & -J_{n}(k_{o}b) & 0 \\ k_{o}J_{n}(k_{o}c) & k_{o}N_{n}(k_{o}c) & -k_{2}J_{n}(k_{2}c) & -k_{2}N_{n}(k_{2}c) & 0 & 0 \\ 0 & 0 & k_{2}J_{n}(k_{2}b) & k_{2}N_{n}(k_{2}b) & -k_{o}J_{n}(k_{o}b) & 0 \\ J_{n}(k_{o}a) & N_{n}(k_{o}a) & 0 & 0 & -H_{n}^{(2)}(k_{o}a) \end{bmatrix} \begin{bmatrix} A_{n} \\ B_{n} \\ C_{n} \\ D_{n} \\ E_{n} \end{bmatrix} = 0$$

$$\begin{bmatrix} 18 \\ 18 \\ 2\pi k_{o}a \end{bmatrix}$$

Matrix equation (18) can be solved to obtain coefficients $A_n ext{...} F_n$ for a given order n.

Richmond (Ref. 23:338) gives results for scattering by the cylindrical shell in terms of echo width per wavelength. To make a comparison to his results the equation for the normalized echo width for this eigenvalue solution is derived. In a two-dimensional problem having linear polarization as that considered here, the echo width can be defined by (Ref 2:358)

$$L_{e} = \lim_{\rho \to \infty} \left(2\pi \rho \left| \frac{\overline{E}^{s}}{\overline{E}_{r}^{\dagger}} \right|^{2} \right)$$
 (19)

The total field at some point in the far zone is the sum of the incident field at that point due to sources without the obstacle present and the scattered field due to the polarization currents impressed upon the obstacle by the sources

$$\overline{E} = \overline{E}^{S} + \overline{E}^{f} \tag{20}$$

The scattered field in (19) is determined by (20). The reference field, \overline{E}_{r}^{1} , in (19) will be assumed to be the incident field at the center of the obstacle without the obstacle present, for consistency with Richmond (Ref. 23).

The large argument asymptotic expansion for the Hankel function of the

second kind (Ref. 25:364)

$$H_{n}^{(2)}(k_{o}^{\rho_{o}}) \xrightarrow{k_{o}^{\rho \to \infty}} \sqrt{\frac{2}{\pi k_{o}^{\rho_{o}}}} e^{-j[k_{o}^{\rho_{o}} - (2n+1)\pi/4]}$$

$$|k_{o}^{\rho}| >> n$$
(21)

can be used to rewrite the total field as

$$E_{z}(\rho_{0},\phi_{0}) \approx -j\omega\mu \sqrt{\frac{2}{\pi k_{0}\rho_{0}}} e^{-jk_{0}\rho_{0}} \sqrt{j\sum_{n=0}^{\infty}} F_{n}e^{j\frac{n\pi}{2}} \cos(n\phi_{0})$$
 (22)

Recall that in (22) the far-zone observation point (ρ_0,ϕ_0) is relative to the origin at the center of the obstacle, and

$$\rho_0 = \frac{2D^2}{\lambda} \tag{23}$$

where D is the diameter of the obstacle.

The incident field, \overline{E}^{i} , can be written as (Ref. 2:236)

$$E_{\frac{1}{2}}^{\dagger}(\rho,\phi) = -\frac{k_0^2 I}{4\omega\epsilon_0} H_0^{(2)}(k_0^{\rho} \rho_n)$$
 (24)

In (24) ρ_n is the distance from the source to the observation point (ρ,ϕ) , or equivalentally (X,Y), and is written as

$$\rho_{n} = \sqrt{(X-X')^{2} + (Y-Y')^{2}}$$
 (25)

which in the far-zone can be written as (see Appendix C)

$$\rho_{\mathbf{n}} \approx \rho - \mathbf{a} \cos \phi \tag{26}$$

Again, the large argument asymptotic expansion can be used

$$H_{o}^{(2)}(k_{o}^{\rho}n) \xrightarrow{k_{o}^{\rho}n \to \infty} \sqrt{\frac{2}{\pi k_{o}(\rho-a\cos\phi)}} e^{-j[k_{o}(\rho-a\cos\phi)-\pi/4]}$$
(27)

In (32) ρ >>a which allows (32) to be written as

$$H_0^{(2)} (k_0 \rho_n) \xrightarrow{k_0 \rho_{n \to \infty}} \sqrt{\frac{2}{\pi k_0 \rho}} e^{-jk_0 \rho} \sqrt{j} e^{jk_0 a \cos \phi}$$
 (28)

Substituting (28) in (29)

$$E_{z}^{i}(\rho,\phi) \approx \frac{-k_{o}^{2}I}{4\omega\epsilon_{o}} \sqrt{\frac{2}{\pi k_{o}^{p}}} e^{-jk_{o}^{p}} \sqrt{j} e^{jk_{o}a\cos\phi}$$
 (29)

From (17), (20), and (29) the scattered field at the far-zone point is

$$E_{z}^{s}(\rho,\phi) = \sqrt{\frac{2}{\pi k_{0} \rho}} e^{-jk_{0} \rho} \sqrt{j} \left(-j\omega\mu\right) \sum_{n=0}^{\infty} F_{n} e^{j\frac{n\pi}{2}} \cos(n\phi)$$
 (30)

The incident field at the center of the obstacle without the obstacle present, \overline{E}_r^i , is also given by (24), but ρ_n now becomes the distance from the source to the origin

$$\rho_n = |a|$$

The large argument asympototic expansion cannot be used in this case since the observation point is not in the far-zone. \overline{E}_r^i can be written as

$$E_{z_{r}}^{i} = \frac{-k_{o}^{2}I}{4\omega\epsilon_{o}} \left[J_{o}(k_{o}a) - j N_{o}(k_{o}a)\right]$$
(31)

where

$$H_n^{(2)}(z) = J_n(z) - j N_n(z)$$
 (32)

Substituting (30) and (31) into (19), dividing by λ_0 , and simplifying, the echo width normalized to the free space wavelength can be written as

$$Le/\lambda_{0} = \frac{8\varepsilon_{0}^{2}c^{4}}{\pi^{3}f^{2}I^{2}} \frac{1}{J_{0}^{2}(k_{0}a) + N_{0}^{2}(k_{0}a)} \left| -j\omega_{n=0}^{\infty} F_{n} e^{j\frac{n\pi}{2}} \cos(n\phi) + \frac{\omega\mu_{0}I}{4} e^{j(k_{0}a\cos\phi)} \right|^{2}$$

$$(33)$$

where

$$C = \frac{1}{\mu_0 \epsilon_0} \approx 3 \times 10^8 \text{ m/sec}$$
 (34)

Equation (33) is a relatively simple representation for the echo width per wavelength. To evaluate the equation for specific parameters in principle requires evaluation of an infinite sum involving constants, F_n , which

must each first be calculated by solution of (18). The analysis to this point presumes the existance of an "exact solution" represented as an infinite summation. If this infinite summation is an exact representation of a sable situation, it must be covergent to the exact solution. If the summation is absolutely convergent, truncation after a finite number of terms will result in a bounded error. The magnitude of the error will depend on the number of terms retained. This method of evaluation through truncation is made use of in the program in Appendix F. The error produced by truncation will be addressed later in this paper.

B. Moment Method Solution

In the previous section a solution for the scattering by the dielectric obstacle was obtained from an exact solution to the Helmholtz equation. Consider now an inhomogeneous region V containing source \overline{J}^i and \overline{M}^i as shown in Figure 8.

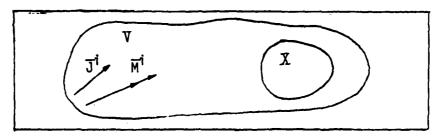


Figure 8. Region V containing sources and obstacles Within region V the following must hold

$$-\overline{\nabla} \times \overline{E} = \hat{z}_{o} \overline{H} + \overline{M}^{\dagger}$$

$$\overline{\nabla} \times \overline{H} = \hat{y}_{o} \overline{E} + \overline{J}^{\dagger}$$
(35)

Where the admittivity, $\hat{y}_0 = j_{\omega \epsilon_0}$, and the impedivity, $\hat{z}_0 = j_{\omega \mu_0}$, are functions of position. If most of the region V is homogeneous except for some small subregion(s), \hat{X} , region V can be defined as all of V excluding V. Within region V then \hat{z}_{0_W} and \hat{y}_{0_W} are constant. Equation (35) can be written as

$$-\overline{\nabla} \times \overline{E} = \hat{z}_{0_{W}} \overline{H} + \overline{M}^{e}$$

$$\overline{\nabla} \times \overline{H} = \hat{y}_{0_{W}} \overline{E} + \overline{J}^{e}$$
(36)

where

$$\overline{M}^{e} = (\hat{z}_{o} - \hat{z}_{o_{\overline{W}}}) \overline{H} + \overline{M}^{f}$$

$$\overline{J}^{e} = (\hat{y}_{o} - \hat{y}_{o_{\overline{W}}}) \overline{E} + \overline{J}^{f}$$
(37)

 \overline{J}^e and \overline{M}^e are the effective currents and can be treated as source currents radiating in a homogeneous region. For the problem being considered $\hat{z}_{o_{a_a}}$ and

 $\hat{\mathbf{y}}_{\mathbf{0}_{\mathbf{W}}}$ are the free space parameters with $\hat{\mathbf{p}}=\hat{\mathbf{p}}$ and $\sigma \sim 0$ so that

$$\overline{J}^{e} = \overline{M}^{i}$$

$$\overline{J}^{e} = j_{\omega}(\hat{\varepsilon} - \varepsilon_{0}) \overline{E} + \overline{J}^{i}$$
(38)

The situation shown in Figure 9 is equivalent then to that of Figure 8.

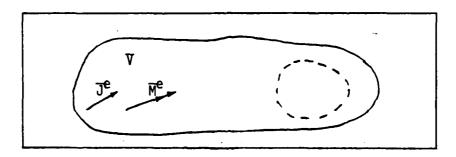


Figure 9. Equivalent sources radiating in a homogeneous region V. The total field in region V is given by

$$\overline{E} = \overline{E}^{\dagger} + \overline{E}^{S} \tag{39}$$

The incident field, \overline{E}^{\dagger} , upon the obstacle (subregion X) is produced by \overline{J}^{\dagger} outside the obstacle while the scattered field, \overline{E}^{5} , is produced by polarization currents, \overline{J}^{p} , induced throughout the obstacle.

$$\overline{J}^{p} = j_{\omega}(\varepsilon - \varepsilon_{0}) \overline{E}$$
 (40)

In (40) \overline{E} is the field induced throughout the obstacle.

As in the development of the eigenvalue solution, the incident field, from the electric current filament parallel to the z-axis, will have only an \hat{z} -component. The \hat{z} -component of incident field will produce a scattered field having only an \hat{z} -component and meeting all boundary conditions. From (39) the total field will also have only an \hat{z} -component. The result then is an incident field from the filament source (see Figure 6) in all space. The obstacle can be replaced by the polarization currents induced on the obstacle radiating in free space. The superposition of the fields produced

is the total field existing in free space.

The field from an electric current filament is given by

$$d\overline{E} = \frac{k^2}{4\omega\epsilon_0} H_0^{(2)}(k\rho) dI \hat{z}$$
 (41)

From (40) the scattered field is

$$dE_z^S = \frac{k^2}{4\omega\epsilon_0} H_0^{(2)} (k\rho) dI$$
 (42)

where

$$dI = \overline{J}^{p} ds' = j\omega(\hat{\epsilon} - \epsilon_{0}) \overline{E} ds'$$
 (43)

and

$$k^2 = k_0^2$$

In (43) \overline{E} is the total field within the obstacle which has only a z-component, and ds' is the increment of surface area on the cross section of the obstacle. (The prime on ds' indicates source coordinates.) Integrating (41) over the surface of the obstacle and substituting (43) for dI, the scattered field from a dielectric of low loss tangent is

$$E_{z}^{s}(x,y) = -\frac{k_{o}^{2}}{4\omega\varepsilon_{o}} \int_{S'}^{S'} j\omega(\varepsilon-\varepsilon_{o}) E_{z}(x',y') H_{o}^{(2)}(k_{\rho}) dx'dy'$$

$$= -\frac{jk^{2}}{4} \int_{S'}^{S} (\varepsilon_{r}-1) E_{z}(x',y') H_{o}^{(2)}(k_{\rho}) dx'dy'$$
(44)

where

$$\varepsilon_{\mathbf{r}} = {}^{\varepsilon}/{}_{\varepsilon_{\mathbf{0}}}$$
 (45)

$$\rho = \sqrt{(x-x')^2 + (y-y')^2}$$
 (46)

and (x,y) is the observation point while (x',y') is the source point.

From (39) and (44)

$$E_z(x,y) = E_z^{\dagger}(x,y) + (-\frac{jk^2}{4}) //_{S_1} (\epsilon_r - 1) E_z(x',y') H_0^{(2)} (k_0 \rho) dx'dy'$$
 (47)

The procedure now is to divide the cross section of the obstacel into N

'square' cells small enough so that ϵ_r and the field intensity are essentially constant over each cell (refer to Figure 10). Enforcing (44) at the center of each cell m results in

$$E_{z_m} + \frac{jk^2}{4} \sum_{n=1}^{n} (\epsilon_n - 1) E_{z_n} f_{cell} n H_o^{(2)} (k_o^{\rho}) dx'dy' = E_{z_m}^{i}$$
 (48)

where

$$\rho = \sqrt{(x'-x_m)^2 + (y'-y_m)^2}$$
 (49)

$$\varepsilon_{n} = \varepsilon_{r} (x_{n}, y_{n})$$
 (50)

$$E_{z_n} = E_{z}(x_n, y_n) \tag{51}$$

and $\mathbf{E}_{\mathbf{Z}_{\mathbf{n}}}$ is the field intensity at the center of each cell n.

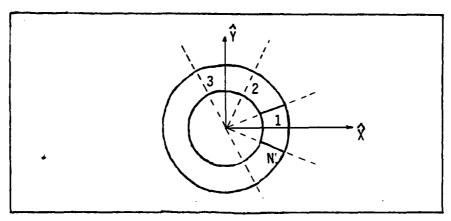


Figure 10. Dividing the obstacle into N nearly square cells.

Equation (48) states that the total field at some cell m is due to the incident field at that cell plus the scattered field from all N cells (including cell m) at cell m. Yet, (48) is one equation with N unknowns. To solve for these N unknown (48) is enforced at the center of all N cells, resulting in N equations in N unknowns. This process of enforcing the integral equation (44) at the centers of N cells is called Point-Natching and is a special case of the method of moments (Ref. 21:312).

The evaluation of (48) involves an integration over a square surface of

the Hankel function of the second kind of order zero. A singularity exists when the argument of the Hankel function approaches zero, which occurs when the source point approaches the observation point. This singularity is integrable (see Appendix D) if the square surface is replaced by a circular surface of equal area with radius \mathbf{a}_n . The result is

$$\frac{jk^{2}}{4} \int_{0}^{2\pi} \int_{0}^{a} H_{0}^{(2)}(k_{0}^{\rho}) \rho' d\rho' d\phi' \\
= (j/2) \left[\pi k_{0}^{a} H_{1}^{(2)}(k_{0}^{a} h_{0}) - 2j\right], m = n$$

$$= \frac{j\pi k_{0}^{a} h_{0}}{2} J_{1}(k_{0}^{a} h_{0}) H_{0}^{(2)}(k_{0}^{\rho} h_{0}), m = n$$
(52)

where ρ is given by (49) and

$$\rho_{mn} = \sqrt{(\chi_{m} - \chi_{n})^{2} + (\gamma_{m} - \gamma_{n})^{2}}$$
 (53)

The polar coordinates ρ' and φ' are based on a coordinate origin at the center of cell n, the source point contributing to the total scattered field at cell m.

For the geometry shown in Figure 6 the matrix equation given by (47) will be symmetric applying (52) for m = 1,2,3...,N. It is obvious that the diagonal terms, m = n, will be equal and the off-diagonal terms depend only upon the distance between the source and observation point. The symmetry inherent in this geometry results in a Toeplitz matrix (Ref. 21:340). This specialization to a Toeplitz matrix is very advantageous when inversion of large matrices is necessary and will be discussed later in this paper.

Once the matrix equation has been solved for the field induced within the dielectric (44) can be used to obtain the scattered field in the far field. Applying the method of point matching, (44) can be rewritten as

$$E_{z}^{s}(x,y) = -\frac{j\pi k_{0}}{2}\sum_{n=1}^{N}(\epsilon_{n}-1)E_{n}a_{n}J_{1}(k_{0}a_{n})H_{0}^{(2)}(k_{0}\rho_{n})$$
 (54)

Note that in (54) the fact that the observation point is in the far field guarantees that it will be different from the source point on the obstacle so that the appropriate integral for $m \neq n$ of (52) is used and

$$\rho_{n} = \sqrt{(X - X_{n})^{2} + (Y - Y_{n})^{2}}$$
 (55)

From Appendix C the distance from the source point on the obstacle, (X_n, Y_n) , to the observation point in the far field, (X, Y), can be written as

$$\rho_{n} = \rho_{o} - \chi_{n} \cos\phi - \gamma_{n} \sin\phi \tag{56}$$

where ρ_0 and ϕ are the polar coordinates of the observation point in the far field. Because the observation point is in the far field, the large argument asymptotic expansion for the Hankel function of order zero (Ref. 25:364) given by (57) can be used.

$$H_0^{(2)}(k_p) \rightarrow \sqrt{\frac{2}{\pi k_p}} e^{-j[k_p - \pi/4]}$$
 (57)

Since $\rho_0^{>>} X_n$ and $\rho_0^{>>} Y_n$, the result is

$$H_{o}^{(2)}(k_{o}\rho_{o}) = \sqrt{\frac{2}{\pi k_{o}\rho_{o}}} e^{-j[k_{o}(\rho_{o} - X_{n}\cos\phi - Y_{n}\sin\phi) - \pi/4]}$$
 (58)

Substituting (58) into (54).

$$E_{z}^{S}(X,Y) \approx -j\sqrt{\frac{\pi k_{o}}{2\rho_{o}}} e^{-jk_{o}\rho_{o}} \sum_{n=1}^{N} (\epsilon_{n}-1) E_{n} a_{n} J_{1}(k_{o} a_{n})$$

$$\cdot e^{j[k_{o}(X_{n}\cos\phi + Y_{n}\sin\phi) + \pi/4]}$$
(59)

As was done for the eigenvalue solution, the echo width per wavelength can be determined using (59) and (19), which is rewritten here for convenience

$$L_{e}/_{\lambda} = 1/_{\lambda} \lim_{\rho \to \infty} \left(2\pi\rho_{o} \left| \frac{\overline{E}}{\overline{E}^{i}} \right|^{2}\right)$$
 (19)

The incident field referred to in (19) is a constant field intensity to which the scattered field is normalized. So that comparison of results can be made to Richmond (Ref. 23:338), this incident field is taken to be that at the center of the dielectric shell with the obstacle removed, radiated from the electric filament line source. This incident electric field is given by Harrington (Ref. 2:236) and is

$$E_{z}^{\dagger} = -\frac{k_{o}^{2}I}{4\omega\varepsilon_{o}} H_{o}^{(2)}(k_{o}|\rho-\rho'|)$$
(60)

where $|\rho-\rho'|$ is the absolute distance from the source to the center of the obstacle and is relatively small compared to ρ_0 . Therefore, (19) is written as

$$L_{e/\lambda} = \lim_{\rho_o \to \infty} \left(2\pi\rho_o \left[-\frac{j\pi k_o}{2\rho_o} e^{-jk_o\rho_o} \sum_{n=1}^{N} (\epsilon_n - 1)E_n a_n J_1(k_a a_n) e^{j[k_o(X_n\cos\phi + Y_n\sin\phi)]} \right]^2 - \frac{\delta_o^2 I}{4\omega\epsilon_o} H_o^{(2)}(k_o|\rho-\rho'|)$$

$$= \pi^{2} k_{o} \left[\frac{\sum_{\Sigma}^{N} (\varepsilon_{n}^{-1}) E_{n} a_{n} J_{1}(k_{o} a_{n}) e^{j[k_{o}(X_{n} \cos\phi + Y_{n} \sin\phi)]}}{\frac{-k_{o}^{2} I}{4\omega\varepsilon_{o}} H_{o}^{(2)}(k_{o}|\rho-\rho'|)} \right]$$
(61)

It is also possible to obtain the total field in the far field by adding (60), evaluated at $\rho = \rho_0 \hat{\rho} + \phi \hat{\rho}$, and (58). It should be noted that the far field is determined using

$$\rho_0 = \frac{2D^2}{\lambda} \tag{62}$$

where D is the diameter of the obstacle and λ is the free space wavelength.

IV. Procedure to Arrive at Numerical Results

A. The Eigenvalue Solution

The theory and derivation behind both the eigenvalue solution and the moment method solution are not overly complex, but several complexities were realized in attempting to obtain numerical results from these solutions. The eigenvalue solution involves an infinite series of coefficients multiplying Hankel functions. The coefficients are arrived at by solving six simultaneous equations. Each equation is comprised of Bessel functions of the first and second kind, Hankel functions of the second kind, and the derivatives of each. How to calculate the Bessel and Hankel functions, how to perform the matrix inversion and how to work with the infinite series were the three major questions to be answered to obtain numerical results from the eigenvalue solution.

Calculating the Bessel and Hankel Functions

Evaluation of the eigenvalue solution requires calculation of Bessel functions of integer order and of widely varying argument. An argument as small as 1.57, involved in obtaining results to compare to Richmond's results (Ref. 23:338), had to be handled as well as those as large as 190, to produce answers for a scatterer of 60 wavelengths cross section. Another concern, in addition to range, was how to calculate the value of these functions efficiently. The matrix equation (23) would theoretically have to be solved an infinite number of times which meant evaluating the elements of the matrix an infinite number of times. Easily, a routine to calculate these functions could consume too much CPU time to approximate the summation. A third area of concern was for the accuracy in evaluating the functions.

A routine based on equations given by Abramowitz (Ref. 25:369) was first obtained. This routine involved calculating Bessel functions of the first and second kind of order zero and one using polynomial approximations appropriate to the argument. Using recurrence relations, values for the functions at other orders were calculated. The values from this routine were the same to an average of 6 decimal places as those of Table 9.4 (Ref. 25:407) for arguments less than 3. When the argument was increased to 100 accuracy was maintained at an average of 6 decimal places except at the point where the order also became 100. From an order of 100 to about 104 the accuracy dropped to an average of 4 decimal places for an argument of 99.95 (comparisons made with those given by Aiken (Ref. 26)). Then the accuracy returned to an average of 6 decimal places for order greater than 104. The program was checked to determine why such a lack of accuracy existed for the case of large argument and order being equal. The program followed exactly from the equations given by Abramowitz and no programming errors were detected. One change which was made was to increase the point at which recurison downward began for evaluation of the Bessel function of the first kind. The program had been designed to begin recurison from an order 10 greater than the order desired. That starting point was increased to 20, 40, and 80 above the order desired. No change at all was detected by increasing even to the 40 point, but the change to the 80 point resulted in the development of significant errors. The errors were seen as exponents of -23 multiplying the value of the function for argument and order being large and equal. This error could have been the result of the normalization value (Ref. 25:385) becoming very large and exceeding the limit of the machine when divided into the trial values the result was very small numbers of exponent -23.

The problem with the previous Bessel routine was not investigated

further mainly because it was not an economical routine to use. It would return values of $J_n(x)$ and $N_n(x)$ for only one order at a time and would therefore have to be called some 2100 times for the scatterer of sixty wavelengths. Another routine was obtained; it calculated the zero and first order terms in the same way as the previous routine did, but it used what is called "continued fraction formulae" (Ref. 27:153). This approach results directly from the recurrence relations, and it produced no more accuracy than the preceeding routine except at equal large argument and larger order. At that point accuracy was maintained at an average of 4 to 5 decimal places. The attractive feature of this routine was that it would pass an array of values starting from the order desired down to order zero, resulting in fewer required calls. Yet, because of the array size and the number of arrays required, core limitations were exceeded on the machine used. Another problem with this routine was that it would not return correct values for the Bessel function of the second kind having arguments less than 17.5. This problem was corrected, but because the routine actually consisted of four separate subroutines and a lot of core was required, the first routine was used to try to obtain some type of answers for this eigenvalue solution.

Matrix Inversion

With the matrix formed it now had to be inverted to solve for the coefficients. There are several methods available in the literature to accomplish matrix inversion; Gaussian Elimination, Gaus-Seidel, and Gaus-Jordan are three typical methods (Ref. 24, 25). But, for matrices of order n>2 a method known as Cholesky's method (also named Crout reduction) "requires fewer arithmetic operations" than either of the three mentioned methods, "making it the fastest of the basic elimination methods" (Ref. 24:198). It is a lower-upper triangular decomposition method and can be made economical of

core by storing the lower and upper triangular matrices in the same area allocated to the matrix to be inverted. This method results in a simple, fast program for matrix inversion.

The Infinite Series

As discussed in the development of the eigenvalue solution, the infinite summation must converge to the exact answer. In order to determine the accuracy of the truncated summation, the behavior of the coefficient for increasing order must be considered. A definite bound on the error due to truncation was not determined, yet the computer generated numbers for the coefficient F_n did show that F_n became purely imaginary and then approached zero for increasing order, as was predicted. Approximately 350 terms were needed in the sum before additional terms became insignificant relative to some ε for a structure of 60 wavelength diameter. It was opted to proceed with the programming, working with the truncated infinite series as described, in order to obtain some type of results.

B. The Moment Method Solution

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The most serious obstacle in obtaining numerical results from the moment method solution was the demand for core. The matrix to be inverted became quite large for a large geometry since the number of cells must increase to maintain accuracy in the final answer. Also, to keep the program as general as possible so that characteristics of the obstacle, such as size and shape, might be changed, the program was written as a collection of separate subroutines. This programming method called for other arrays in addition to the matrix to be set up which quickly exceeded the amount of core available to the program. Fitting the program in the available core and obtaining

reasonable execution time were two pressing problems in programming the moment method solution.

Core Requirements

In developing the theory for the moment method solution, it was mentioned that the symmetry of this particular problem would yield a Toeplitz matrix. Numbers were generated for a simple case and showed that indeed the matrix was Toeplitz in form. This was a significant observation since routines exist which take advantage of this special form. The routine chosen to be used (see Appendix G) does not require the passing of the entire matrix to be inverted but only the first row or first column of the matrix. Overall the routine requires only five arrays of dimension n where n is the dimension of the square matrix. This results in a significant reduction in the demand for core.

To combat the core requirements due to programming by use of subroutines a feature called Extended Memory Area (EMA) was utilized. All arrays were first defined to be in a common block; that common block was then defined to be in EMA. Basically, EMA is disk memory as opposed to core memory. A compiled program is loaded into core to be run, and arrays which are not specified to be in EMA are allocated space in core. Only so much core can be taken up by any particular program, 64K for the HP 21MX M series; if more core is asked for, the loader aborts and the program cannot be run. EMA allows the program to be loaded and run, but it also has limitations.

Processing Time

EMA, in conjunction with designating a large background when loading, will allow a large program to be loaded and run, but it also requires more

processing time. The system has to swap data in EMA from disk to core in order to process the data as directed by the main program. This swapping takes up much more computer time than working with data already in core. For the size of the arrays required to analyze a large structure of 60 wavelength cross section run time exceeded two hours. Obviously, this was a costly program to run on this minicomputer as programmed.

C. The Priority Set for Both Methods

The intent was still to produce two independent computer solutions for the scattering from a dielectric cylinder of circular cross section and to form an argument for their validity. In an attempt to meet this goal the preceding concerns were incorporated into two programs. Not all questions were answered nor were all the concerns met. A discussion of the results from these two programs follows along with conclusions and recommendations on how to improve upon them.

V. Discussion of Results

Computer generated output appears in Appendix E, including plots of the scattered and total field for a number of trials. As emphasized throughout this paper, the goal has been to generate numerical results from the two methods discussed, to compare those results to Richmond's results (Ref. 23: 338), and to increase the size of the structure to model an actual radome. In the process an argument for the validity or invalidity of the answers plus a discussion of problems encountered would be presented. Looking at Figures E-2, E-3, and E-4 along with Table E-1, it is evident that the results are very close to being the same for the small structure of 0.6 wavelength cross section. The fact that equivalent results were obtained from the two completely different methods seems to indicate that the error due to the truncation of the sum in the eigenvalue solution was not a significant determinant of the final answer. Both programs calculated the Bessel functions using the same routine with the accuracy problems discussed previously. The results thus obtain credibility because these two methods, which were independent and very different, resulted in comparable answers.

Before ever attempting any calculations one would probably assume that a small obstacle of 0.6 wavelength cross section would cause very little disturbance of the field incident upon it. Figures E-5 and E-6 are consistent with this assumption, showing a very smooth, slight variation over 360°. This structure does not possess any abrupt changes in curvature; therefore, a wave which might be trapped by the structure would radiate consistently as it traveled around the structure. As the trapped wave radiated it would be losing energy and would in turn have less and less to radiate. What difference a trapped wave would present is not evident in this trial, but this

argument is consistent with the smooth variation of the total field. It is also possible to view this problem as a superposition of a circular array of line dipoles and a line source radiating in free space. This is a physical picture of the moment method solution. Two dipoles having some current distribution on them and spaced a distance d apart will produce nulls in their radiation pattern about $^{\lambda}/d$ radians apart. The maximum distance d for this first trial is $2c = 0.6\lambda$. Therefore, nulls should appear in the scattered field spaced by approximately 1.67 radians or 95.5°. Looking at Figure E-3, the nulls appear to be spaced by about 110°.

The outer diameter of the obstacle was increased 10 fold for the second trial. The thickness of the dielectric was kept at 0.05λ and the distance from the outside of the obstacle to the location of the line source was kept at 0.2λ . Since the first trial compared closely using 37 cells to approximate the cylindrical shell, 370 cells was used in the second trial to maintain close to the same cell density per wavelength. A comparison of Figures E-7 and E-8 and Figures E-9 and E-10 shows equivalent results existing again for the two different methods. A couple of slight differences do exist though. First, the magnitude of the results from the moment method solution are noticably less than those from the eigenvalue solution. Round off errors, incorrect evaluation of the Bessel functions, and/or a nonoptimum number of cells could account for this small difference. The second difference is that the total field of Figure E-9 shows a sudden drop at about 152.5° and then a sudden increase about 2.5° later. This also occurs at about 207.5°. Figure E-10 shows a smooth variation in the total field in these regions. The eigenvalue results do not show a squiggle in the pattern at 172.5° and 187.5°, as do the moment method results. Both polar plots were plotted at every 1° so the difference is not due to resolution.

An interesting observation can be made by overlaying Figures E-5 and E-9 and Figures E-6 and E-10 as shown in Figures E-11 and E-12 respectively. After increasing the cylinder diameter the result appears to be that the general shape of the total field pattern remains the same. Effectively, the circular array spoken of previously has been increased in size and more dipoles added. The nulls should now be spaced about $^{\lambda}/6.0\lambda = 0.167$ radians or 9.55° apart. The addition of dipoles to the array would cause the variation in the gain pattern as seen. With the observations pointed out, it is felt that the results of this trial are also correct.

The third trial was for another 10 fold increase in the geometry. The results from the eigenvalue solution appear in Figures E-13 and E-14. It was not possible to run the moment method program because the need for 3700 cells over extended EMA. An attempt was made to break the obstacle into 3700 cells and to work with on every other cell in computing the total field. The program with this modification would then load and run, but after three hours of run time the program was aborted. (This moment method program slowed the system thown considerably.) Because there is nothing to compare the results of the eigenvalue solution against, only general comments on those results can be made.

Applying the array analysis, the nulls should appear at $^{\lambda}/60\lambda$ = 0.0167 radians or 0.955°. Observing Figure E-12 there are indeed 20 peaks in 20°. A change in the scattered field as compared to the previous two trials is the maximum occurring at zero degrees. This maximum is plotted at about 0.95 in Figure E-13. Having normalized all calculations of the scattered field relative to the maximum magnitude of scattered field, the maximum as plotted should be 1.0 as for trials one and two. This evident error immediately sheds doubt on the validity of the results. Another concern is that the

scattered field pattern has such deep nulls and so many of them. It is hard to predict what is causing such a spiked pattern to exist. Symmetry still holds for the total field in Figure E-14, but again it is difficult to validate the pattern with nothing else to compare to.

VI. Conclusions and Recommendations

The fact that the two different programs produced results comparable to published results for the small structure of 0.6 wavelength diameter gives confidence that these results are correct, thus validating both the approach and the computer program. When the diameter was increased to 6.0 wavelengths, the eigenvalue and moment method results were again nearly the same, except for the small but noticeable difference in magnitudes. Adding some 56 numbers, each from a combination of Bessel functions accurate to only 5 decimal places could contribute significantly to this difference. To determine the degree to which the results are correct, one recommended approach would be to bound the error due to truncation. A second approach would be to run these programs on a system which has a longer word length, so that the machine generated errors will be reduced. An additional reason for going to a larger machine would hopefully be to decrease the run time required by each program and to have more memory to work with. More accurate evaluation of the Bessel functions could also lead to better results.

The two methods studied do present and address some of the complexities encountered in trying to solve the problem. A better understanding of this problem could come from also plotting the magnitude and phase of the incident fields, the field in the dielectric, and the scattered field. This would give an indication of the interactions of the fields producing the total field observed. Yet, the fact remains that the point matching method for the structure of 60 wavelength diameter required more memory than is available to the average system user. Some method for retaining the data generated such as on magnetic tape is needed to circumvent the core limitations. The other methods for reducing the size of the matrix such as Lagrange Interpolation

can be tested.

With results for scattering from the circular obstacle of 6.0 wavelength diameter the scatterer could then be modeled as an ellipse and verified by an essentricity of zero. The essentricity could then be allowed to approach one, which would be a model more representative of the radome of concern. The methods developed to reduce the size of the matrix for the circular obstacle could possibly be manipulated for use with the ellipse. The ellipse will present its own problems such as how the cell size should vary around the structure and what effect a very close source (relative to the size of the obstacle) will have. But, these steps should lead to an eventual solution to the secondary lobe seen in the measured antenna patterns.

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Appendix A. The Model and Its Parameters

To model the radome as a dielectric cylinder of circular cross section the radius of curvature of the radome must be determined. Figure A-l shows the geometry for the model and for the approach to be taken.

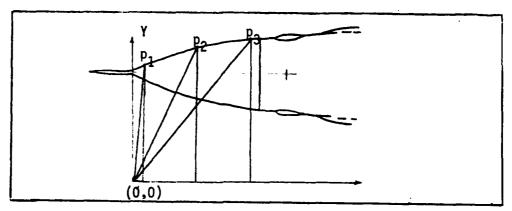
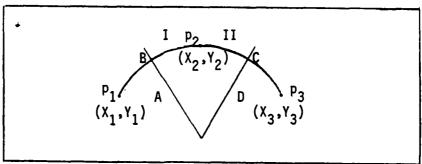


Figure A-1. Model and geometry to determine the radius of curvature of the radome.

A result for the radius of curvature can be obtained using the following procedure.



. Figure A-2. The geometry to be used in solving for the radius of curvature of a circular arc.

The equation for the arc S from p_1 to p_3 is

$$Y-Y_1 = \frac{Y_2-Y_1}{X_2-X_1} \quad (X-X_1)$$
 (A-1)

The equation for vector A which is the perpendicular bisector of the arc from P_1 to P_2 is

$$Y_A = \frac{X_2 - X_1}{Y_2 - Y_1} \quad X_A + b$$
 (A-2)

The midpoint of segment I (B to p_2) is

$$X = \frac{X_1 + X_2}{2}$$
, $Y = \frac{Y_1 + Y_2}{2}$ (A-3)

Substituting (A-3) into (A-2), (X,Y) being the point at which vector A and segment I intersect, yields

$$\frac{Y_1 + Y_2}{2} = \frac{-X_2 - X_1}{Y_2 - Y_1} \left(\frac{X_1 + X_2}{2}\right) + b \tag{A-4}$$

Solving (A-4) for b results in

$$b = \frac{Y_1 + Y_2}{2} + \frac{X_2^2 - X_1^2}{2(Y_2 - Y_1)}$$
 (A-5)

Replacing b in (A-2) by (A-5), the equation for vector A is

$$Y_A = -\frac{X_2 - X_1}{Y_2 - Y_1} X_A + \frac{Y_1 + Y_2}{2} + \frac{X_2^2 - X_1^2}{2(Y_2 - Y_1)}$$
 (A-6)

Similarly, the equation for vector D is

$$Y_{D} = -\frac{X_{3}-X_{2}}{Y_{3}-Y_{2}}X_{D} + \frac{Y_{2}+Y_{3}}{2} + \frac{X_{3}^{2}-X_{2}^{2}}{2(Y_{3}-Y_{2})}$$
(A-7)

Solving (A-6) and (A-7) simultaneously for the point of intersection (h,k),

$$(Y_A = Y_D = k, X_A = X_D = h)$$
, yields

$$-\frac{x_2-x_1}{y_2-y_1} + \frac{y_1+y_2}{2} + \frac{x_2^2-x_1^2}{2(y_2-y_1)} = -\frac{x_3-x_2}{y_3-y_2} + \frac{y_2+y_3}{2} + \frac{x_3^2-x_2^2}{2(y_3-y_2)}$$

or

$$h = \left[\frac{Y_2 + Y_3}{2} + \frac{X_3^2 - X_2^2}{2(Y_3 - Y_2)} - \frac{Y_1 + Y_2}{2} - \frac{X_2^2 - X_1^2}{2(Y_2 - Y_1)} \right] \left[\frac{X_3 - X_2}{Y_3 - Y_2} - \frac{X_2 - X_1}{Y_2 - Y_1} \right]^{-1}$$

and simplifying,

$$h = \frac{1}{2} \left[\frac{(Y_3 - Y_1)(Y_3 - Y_2)(Y_2 - Y_1) + (X_3^2 - X_2^2)(Y_2 - Y_1) - (X_2^2 - X_1^2)(Y_3 - Y_2)}{(X_3 - X_2)(Y_2 - Y_1) - (X_2^2 - X_1)(Y_3 - Y_2)} \right]$$
(A-8)

Knowing h from (A-8), k can be calculated from (E-6) where

$$k = -\frac{x_2 - x_1}{Y_2 - Y_1} h + \frac{Y_1 + Y_2}{2} - \frac{x_2^2 - x_1^2}{2(Y_2 - Y_1)}$$
(A-9)

The equation for the radius of a circle is

$$r = [(X_1 - h)^2 + (Y_1 - k)^2]^{1/2}$$
 (A-10)

Figure A-1 shows the model of the radome as a circular cylinder. The radius of curvature of the cylinder can be arrived at using (A-8), (A-9), and (A-10).

Appendix B. Derivation of the Eigenvalue Solution Matrix

Given the following representations of the vector electric potentials in the indicated regions

$$\frac{\text{REGION}}{0} \qquad \frac{\text{ELECTRIC VECTOR POTENTIAL}}{0} \qquad A_{z_{0,n}} = F_{n}H_{n}^{(2)}(k_{o}^{\rho})\cos(n\phi) \qquad (a)$$

$$I \qquad A_{z_{1,n}} = [A_{n}J_{n}(k_{o}^{\rho}) + B_{n}N_{n}(k_{o}^{\rho})]\cos(n\phi) \qquad (b)$$

$$II \qquad A_{z_{11,n}} = [C_{n}J_{n}(k_{2}^{\rho}) + D_{n}N_{n}(k_{2}^{\rho})]\cos(n\phi) \qquad (c)$$

$$III \qquad A_{z_{111,n}} = E_{n}J_{n}(k_{o}^{\rho})\cos(n\phi) \qquad (d)$$

the following boundary conditions (B.C.'s)

$$\hat{n} \times \overline{E}_{i,n} = \hat{n} \times \overline{E}_{(i+1),n}$$
, $i=0,I,II @ \rho = a,b,c$ respectively (a)
 $\hat{n} \times \overline{H}_{i,n} = \hat{n} \times \overline{H}_{(i+1),n}$, $i=0,I,II @ \rho = c,b$ respectively (b) (P.2)
 $\hat{n} \times \overline{H}_{0,n} - \hat{n} \times \overline{H}_{I,n} = \overline{J}_{S}$ @ $\rho = a$ (c)

and the fact that

$$\overline{E}_{i,n} = E_{Z_{i,n}} \hat{z} = j\omega\mu_0 A_{Z_{i,n}}$$
(B.3)

a matrix can be formed to solve for the six unknowns $A_n ext{...} F_n$. Assume no variation with $(\frac{\partial}{\partial z} = 0)$.

From B.C. (B.2.a) and (B.1) three equations result

$$F_n H_n^{(2)}(k_0 a) = A_n J_n(k_0 a) + B_n N_n(k_0 a)$$
 (B.4)

$$A_n J_n(k_0 C) + B_n N_n(k_0 C) = C_n J_n(k_2 C) + D_n N_n(k_2 C)$$
 (E.5)

$$C_n J_n(k_2 b) + D_n N_n(k_2 b) = E_n J_n(k_0 b)$$
 (B.6)

For the case at hand

$$\overline{H} = -\frac{1}{j\omega\mu_{o}} \left[\frac{\partial E_{z}}{\partial \rho} \hat{\phi} \frac{1}{\rho} \frac{\partial E_{z}}{\partial \phi} \hat{\rho} \right]$$

$$= -\frac{\partial A_{z}}{\partial \rho} \phi - \frac{1}{\rho} \frac{\partial A_{z}}{\partial \phi} \hat{\rho}$$
(B.7)

In both (B.s.b) and (B.2.C) $\hat{n} = \hat{\rho}$ so that

$$n \times \overline{H} = -\frac{\partial A_{z}}{\partial \rho} \hat{z}$$
 (B.8)

From B.C. (B.2.b), (B.1), and (B.8) two more equations result

$$k_0[A_nJ_n'(k_0C)+B_nN_n'(k_0C)] = k_2[C_nJ_n'(k_2C)+D_nN_n'(k_2C)]$$
 (B.9)

$$k_2[A_nJ_n'(k_2b)+B_nN_n'(k_2b)] = k_0E_nJ_n'(k_0b)$$
 (B.10)

The current density is given by

$$\overline{J} = J_z \hat{z} = I\delta(\overline{r}) \hat{z}$$
 (B.11)

where I is the magnitude of the source current and $\delta(\overline{r})$ is the Kronecker delta function. The total current is obtained by integrating over the cross sectional area through which the current density passes

$$I_{Total} = \int_{S} \overline{J} dS = I$$
 (B.12)

Integrating (B.11) over a circular cross section

$$\int_{S} \delta(\overline{r}) ds = 1$$

$$= \int \int \delta(\overline{r}) \rho d\rho d\phi \qquad (B.13)$$

which yields

$$\delta(\overline{r}) = \frac{1}{\rho} \delta(\rho) \delta(\rho) \tag{B.14}$$

At $\rho = a$

$$J_{z} = \frac{1}{\rho} \delta(\rho - a)\delta(\phi) \tag{B.15}$$

where $\delta(\rho-a)$ is the Dirac delta function.

From B.C. (B.2.C), (B.11), (B.8), (B.7), and

$$E_{z_{i}} = \sum_{n=-\infty}^{\infty} -j\omega_{\mu} A_{z_{i}}$$
 (B.16)

(Ref. 1:198)

$$-k_{o} \sum_{n=-\infty}^{\infty} \{F_{n}H_{n}'^{(2)}(k_{o}a)-[A_{n}J_{n}'(k_{o}a)+B_{n}N_{n}'(k_{o}a)]\}\cos(n_{\phi})=J_{s_{z}}$$
(B.17)

The surface current $\mathbf{J}_{\mathbf{S}_{\mathbf{Z}}}$ is obtained by integrating (B.15) over the surface of the source.

$$J_{S_{Z}} = \int \rho \delta(\rho - a) \delta(\phi) d\rho$$

$$= \frac{I}{a} \delta(\phi)$$
(B.18)

The surface current can also be expanded in a complete orthonormal basis set

$$J_{s_{z}} = -k_{0} \sum_{n=-\infty}^{\infty} a_{n} \cos(n\phi)$$
 (B.19)

Equating (B.18) and (B.19)

$$-k_0 \sum_{n=-\infty}^{\infty} a_n \cos(n\phi) = \frac{I}{a} \delta(\phi)$$

or,

$$-\frac{I}{k_0 a} \, \mathring{\sigma}(\phi) = \sum_{n=-\infty}^{\infty} a_n \, \cos(n\phi) \tag{B.20}$$

To apply the rules of orthogonality, multiply both sides of (B.20) by $\cos(m\phi)$ where m, like n, is an integer and integrate over one entire interval 0 to 2π .

$$\int_0^{2\pi} - \frac{I}{k_0 a} \delta(\phi) d\phi = \int_0^{2\pi} \int_{n=-\infty}^{\infty} a_n \cos(n\phi) \cos(m\phi) d\phi$$
 (B.21)

which reduces to

$$-\frac{I}{k_0 a} = \int_0^{2\pi} [a_m \cos(m\phi) \cos(m\phi) + a_{-m} \cos(-m\phi) \cos(m\phi) d\phi$$

$$= \pi a_m + \pi a_{-m}, m \neq 0$$
(B.22)

For $a_m = a_{-m}$, as is the case,

$$a_{m} = \frac{I}{2\pi k_{a}}$$
 (B.23)

If m = 0, (B.22) becomes

$$-\frac{I}{k_0 a} = 2\pi a_0$$

or,

$$a_0 = -\frac{I}{2\pi a k_0} \tag{B.24}$$

Therefore,

$$a_n = -\frac{I}{2\pi a k_0} \quad \text{for all n}$$
 (B.25)

The complete orthonormal basis set could also have been written as

$$J_{s_{z}} = -k_{o} \sum_{n=0}^{\infty} b_{n} \cos(n\phi)$$
 (B.26)

since $cos(n_{\varphi})$ is an even function of $_{\varphi}.$ In the same way as a_n was determined, b_n can be found to be

$$b_n = -\frac{I\varepsilon_n}{2\pi k_0 a}$$
 (B.27)

where

$$\varepsilon_{n} = \begin{cases} 1, & n = 0 \\ 2, & n > 0 \end{cases}$$
 (B.28)

Substituting (B.19) and (B.25) into (B.17), the result is

$$-k_{0} \sum_{n=-\infty}^{\infty} \{F_{n}H_{n}^{(2)}(k_{0}a) - [A_{n}J_{n}^{(k_{0}a)} + B_{n}N_{n}^{(k_{0}a)}]\} \cos(n\phi)$$

$$= -k_{0} \sum_{n=-\infty}^{\infty} -\frac{I}{2\pi k_{0}a} \cos(n\phi) \qquad (B.29)$$

Looking at each term of (B.29) separately yields the sixth equation with which to solve for the unknown coefficients and is

$$A_n J_n'(k_0 a) + B_n N_n'(k_0 a) - F_n H_n^{(2)'}(k_0 a) = -\frac{I}{2\pi k_0 a}$$
 (B.30)

where (B.30) is based on summing from minus infinity to infinity. If the

same procedure is followed using (B.26), (B.27), and (B.28), the equation becomes

$$A_{n}J_{n}'(k_{o}a) + B_{n}N_{n}'(k_{o}a) - F_{n}H_{n}^{(2)'}(k_{o}a) = -\frac{1\epsilon_{n}}{2\pi k_{o}a\epsilon_{n}}$$

$$= -\frac{1}{2\pi k_{o}a}$$
(B.31)

where (B.31) is based on summing from zero to infinity. The six equations derived can be combined to form one matrix equation which can be solved for the six coefficients $A_n \dots F_n$.

Appendix C. Representing the Distance to the Far Zone Observation Point

The distance from the source point to the observation point in the far zone, ρ_n , is shown in Figure C-1. The stipulation that must be made is that the distance to the observation point, ρ_0 , is much much greater than the distance to the source point, ρ . With this condition met, it can be assumed that for an observation point out at infinity the vectors $\overline{\rho}_0$ and ρ_n become almost parallel and therefore $\overline{\rho}_n$ $\overline{\rho}_n'$ (see Figure C-1.).

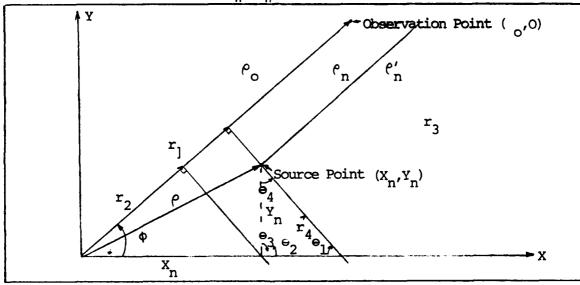


Figure C-1. Geometry for the distance to the observation point in the far field from the source point.

For r_3 parallel to ρ_0 angle θ_2 = ϕ and θ_3 = 90 - ϕ which implies that θ_4 = ϕ . The geometry is such that r_4 = r_4 and

$$r_1 = r_4 = Y_n \sin \phi \tag{C-1}$$

Also,

$$r_2 = X_n \cos \phi \tag{C-2}$$

Using (C-1) and (C-2), it is obvious that

$$\rho_n \sim \rho_n' = \rho_0 X_n \cos \phi - Y_n \sin \phi \qquad (C-3)$$

Appendix D. Integration of the Hankel Function over a Circular Area

Using the moment method to evaluate the total field due to a dielectric cylindrical shell or circular cross section in the presence of a parallel filament line source, the integral in (D-1) must be evaluated (following Richmond (Ref. 23:336)).

$$jk^{2}/_{4}$$
 // H₀(2)(k_p) p' dp' dφ' (D-1)

where

$$\rho = |\rho - \rho'| \tag{D-2}$$

see Figure D-1.

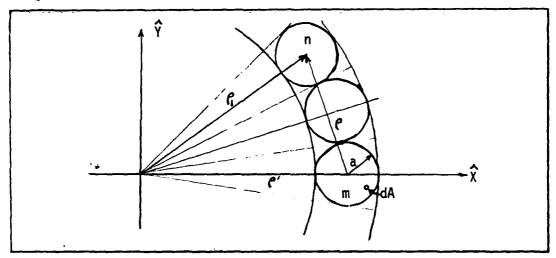


Figure D-1. Division of the obstacle into circular cells.

A singularity exists in evaluating (D-1) when the argument becomes zero or when the source and observation point are one and the same. To evaluate (D-1) for this singularity the integration becomes

$$jk^{2}/_{4}$$
 $\int_{0}^{2\pi} \int_{0}^{a} H_{0}^{(2)}(k_{P}) p' dp' d\phi'$ (D-3)

where

$$H_0^{(2)}(k_p) = J_0(k_p) - j N_0(k_p), p = p'$$
 (D-4)

for a reference point at the center of cell n. Substituting (D-4) into (D-3)

$$jk^{2}/_{4} \int_{0}^{2\pi} \int_{0}^{a} H_{0}^{(2)}(k_{P}') \rho' d\rho' d\phi' = jk^{2}/_{4} \{f_{0}^{2\pi} \int_{0}^{a} \rho' J_{0}(k_{P}') d\rho' d\phi' - j \int_{0}^{2\pi} \int_{0}^{a} \rho' N_{0}(k_{P}') d\rho' d\phi$$

$$(D-5)$$

Two equations from Abramowitz (Ref. 25:484) 11.3.20 and 11.3.24 are

$$\int_0^z t^{\nu} J_{\nu-1}(t) dt = z^{\nu} J_{\nu}(z)$$
 (D-6)

$$\int_{0}^{z} t^{\upsilon} N_{\upsilon-1}(t) dt = z^{\upsilon} N_{\upsilon}(z) + \frac{2^{\upsilon}(\upsilon)}{\pi}$$
 (D-7)

Splitting (D-5) into two parts and substituting (D-6) and (D-7) in, the following steps result:

$$\int_{0}^{2\pi} \int_{0}^{a} \rho' J_{o}(k\rho')d\rho' d\phi' = 2\pi \int_{0}^{a} \rho' J_{o}(k\rho')d\rho'$$

Let

$$t = k_{\rho}'$$
 $dt = kd_{\rho}'$

for

$$\rho' = 0 t = 0$$

$$\rho' = a t = ka$$

$$2\pi \int_{0}^{a} \rho' J_{0}(k\rho') d\rho' = \frac{2}{k^{2}} \int_{0}^{ka} t J_{0}(t) dt$$

$$= \frac{2\pi}{k^{2}} (ka) J_{1}(ka) (D-8)$$

And, as above

$$\int_{0}^{2\pi} \int_{0}^{a} \rho' N_{0}(k\rho')d\rho' d\phi' = \frac{2\pi}{k^{2}} \int_{0}^{ka} t N_{0}(t)dt$$

$$= \frac{2\pi}{k^{2}} \{ka N_{1}(ka) + \frac{2(r)}{\pi}\}$$
 (D-9)

Substituting (D-8) and (D-9) into (D-5), the result is

$$jk^{2}/_{4} \left\{ \frac{2\pi}{k^{2}} [(ka) J_{1}(ka)] - j \frac{2\pi}{k^{2}} [(ka) N_{1}(ka) + \frac{2}{\pi}] \right\}$$

which reduces to

$$j/_2 \{\pi ka \ J_1(ka) - j \ \pi ka \ N_1(ka) - j \ 2\}$$

or

$$jk^2/_4 \int_0^{2\pi} \int_0^a H_0^{(2)}(k_p')_p' d_p' d_{\phi'} = j/_2(\pi ka H_1^{(2)}(ka)-j 2)$$
 (D-10)

for

m = n.

Appendix E. Results

Contained in this appendix are the results generated by the program implementing the eigenvalue solution method and the program implementing the moment method solution.

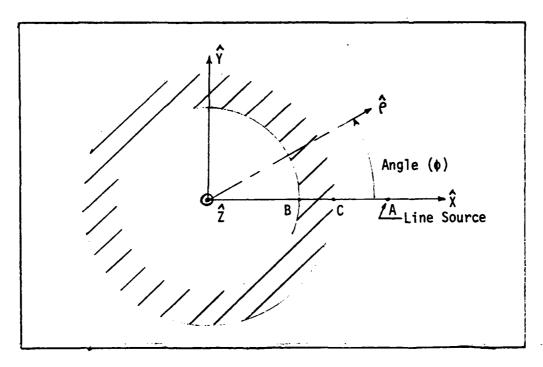


Figure E-1. The geometry used in the computer programs to produce the results contained within this appendix.

For all the results

Permeability $\mu_0 = \mu$ Dielectric Constant $\epsilon_R = 4.0$ Loss Tangent $\tan \theta = 0.0$

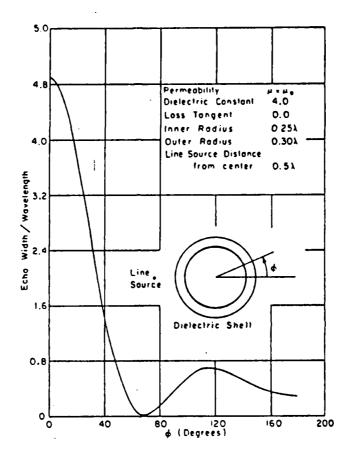


Figure E-2. Scattering pattern of a circular dielectric shell in the presence of a nearby parallel line source, calculated with the in-egral-equation technique.

Reproduced from Richmond (Ref. 23:338)

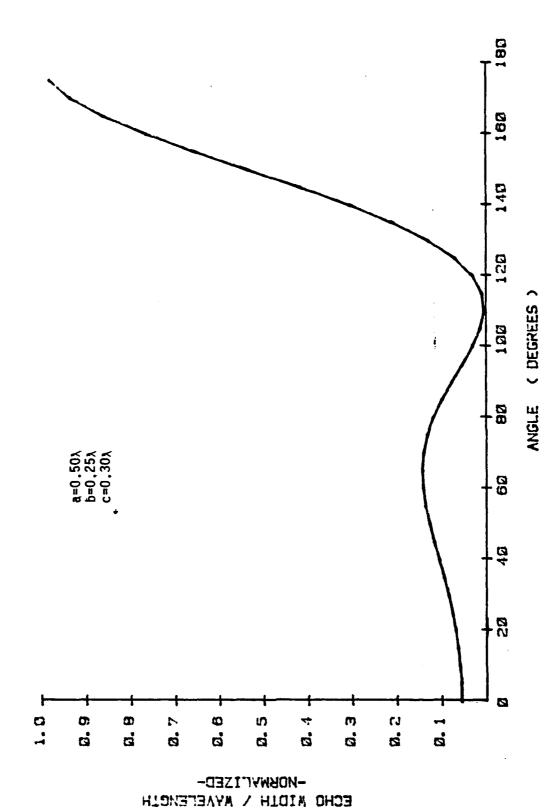


Figure E-3. Scattering pattern using the eigenvalue solution method.

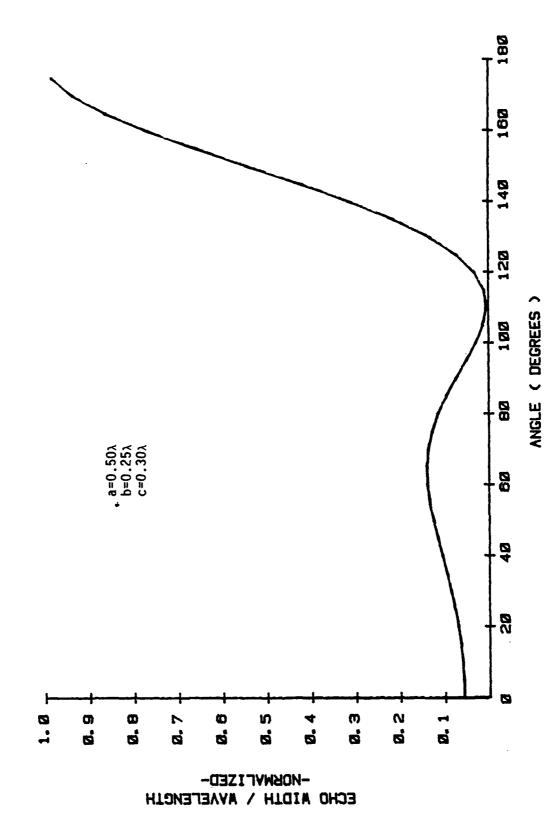


Figure E-4. Scattering pattern using the moment method solution.

TABLE E-I.

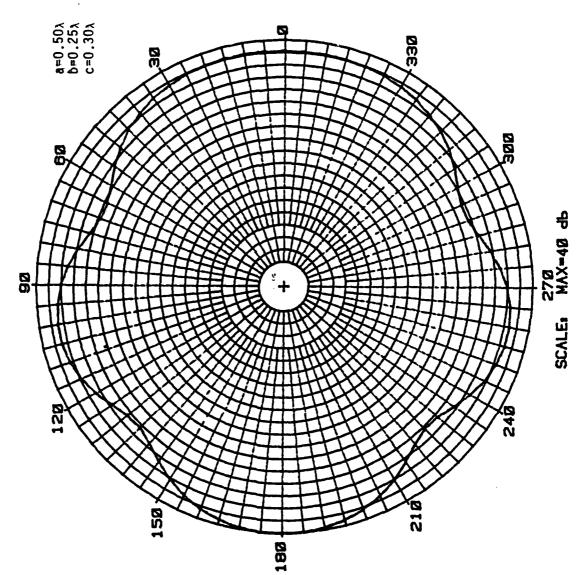
Comparison of the Results from the Eigenvalue and Moment Method Programs to Richmond's Results.

For the three sets of results:

Permeability	µ≐ր
Dielectric Constant	4.0°
Loss Tangent	0.0
Inner Radius	0.25λ
Outer Radius	0.30λ
Line Source Distance	
from Center	0.5λ

Echo Width/Wavelength			
Angle	Richmond	Eigenvalue	Moment Method (37 cells)
0	0.284	0.282	0.289
70	0.697	0.671	0.720
110	0.026	0.022	0.022
180	4.90	4.91	5.11

NOTE: Richmond (Ref. 23:338) placed the line source at 180° while the source was at zero degrees for the computer programs. Flipping Richmond's results over allows the comparison above.



10:

Figure E-5. Total electric field using the eigenvalue solution method.

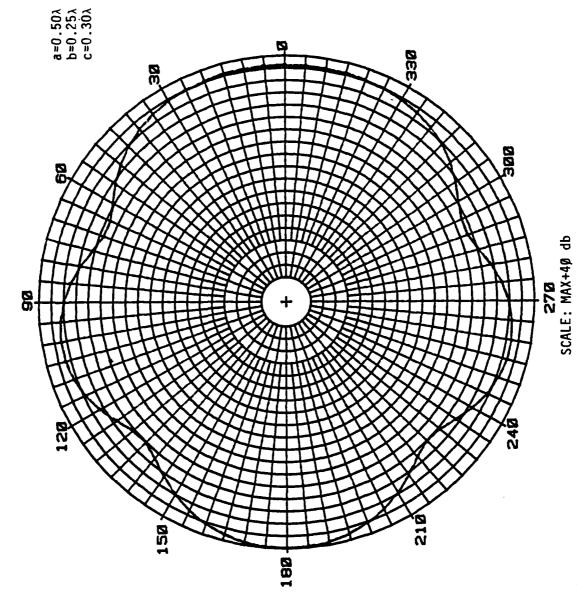
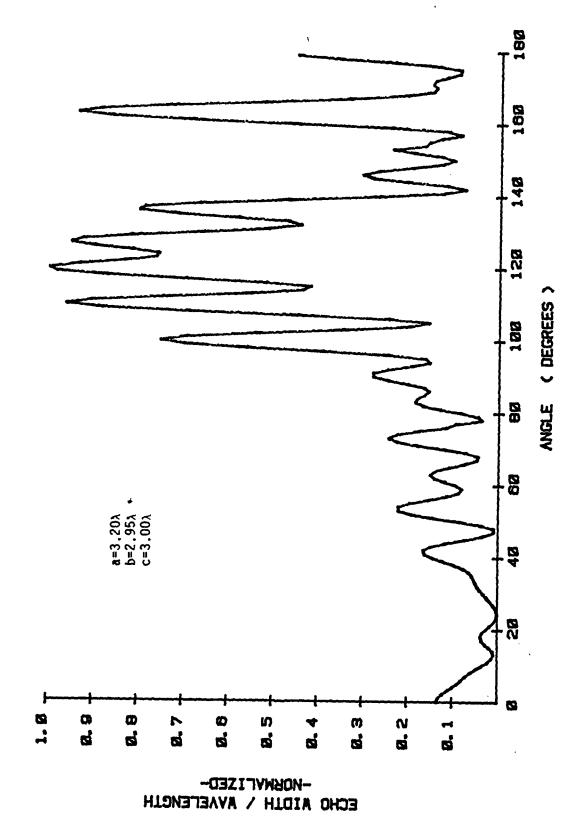
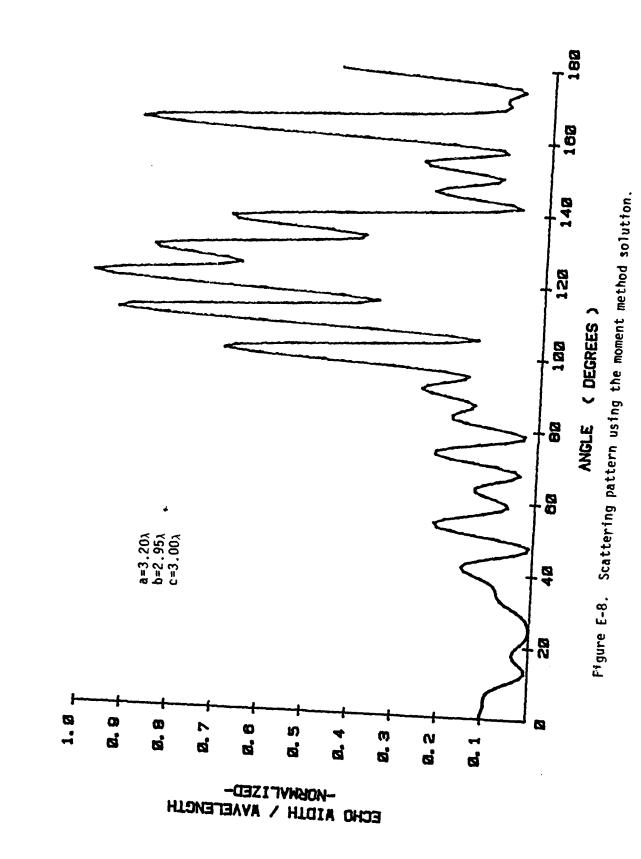
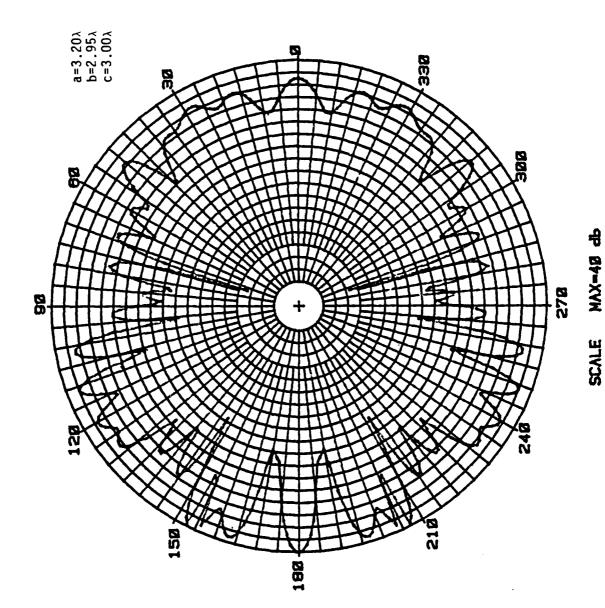


Figure E-6. Total electric field using the moment method solution.



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Total electric field using the eigenvalue solution method. Figure E-9.



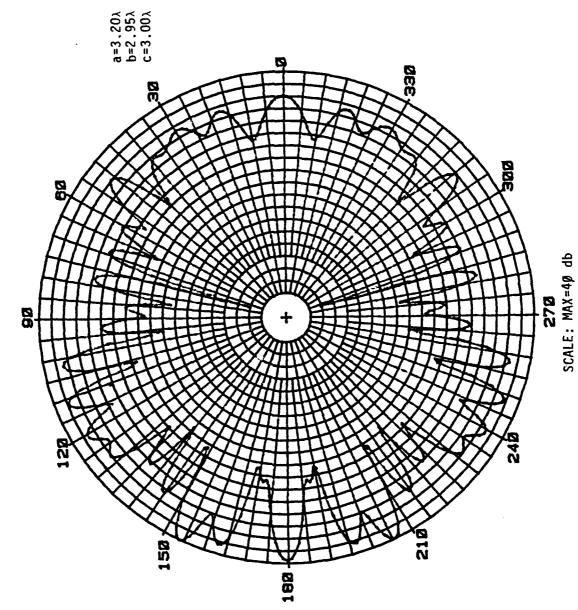
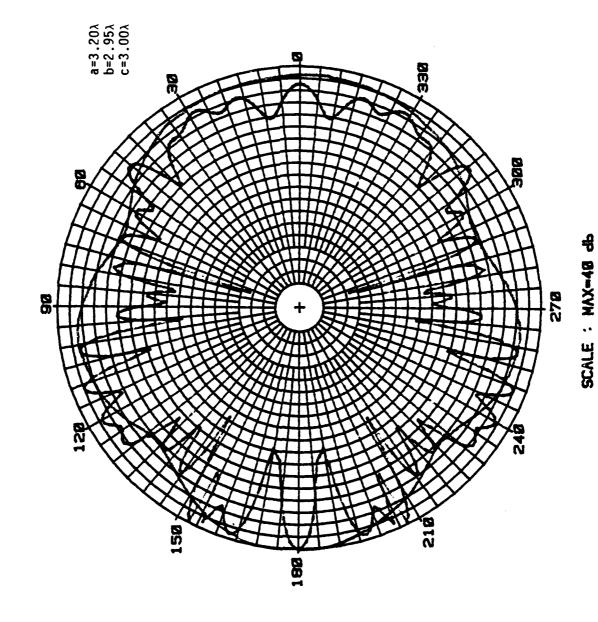
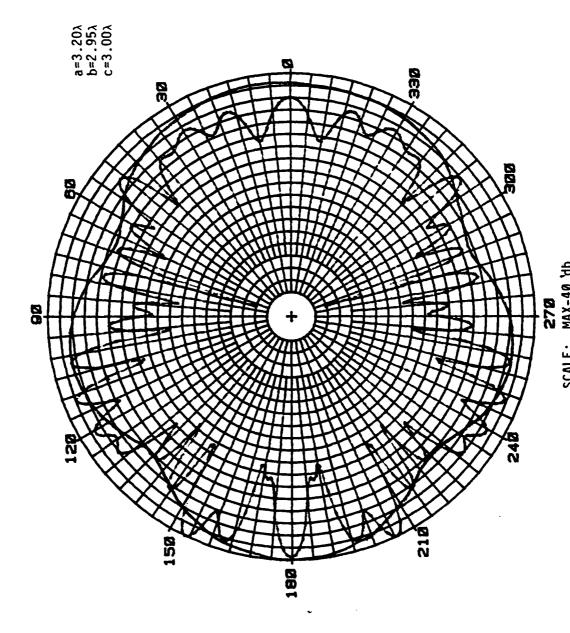


Figure E-10. Total electric field using moment method solution.



Overlaying Figure E-5 on Figure E-9 for the total field using the eigenvalue solution method. Figure E-11.

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SCALE: MAX-40 Wb Overlaying Figure E-6 on Figure E-10 for the total field using the moment method solution. Figure E-12.

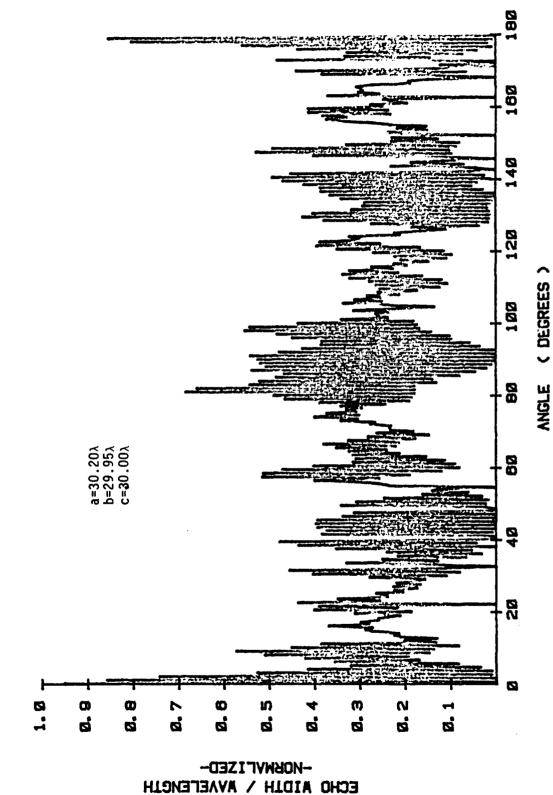


Figure E-13. Scattering pattern using the eigenvalue solution method.

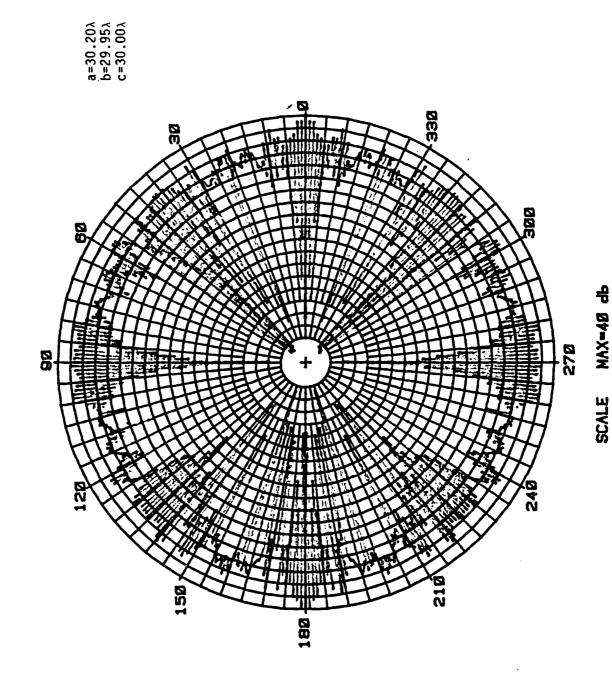


Figure E-14. Total electric field using the eigenvalue solution method.

Appendix F. Computer Program for Eigenvalue Solution Method

This appendix contains the computer program which implements the eigenvalue solution method. The main program, RADMI, the matrix inversion routine, CLSKY, and the routine to calculate the value of Bessel functions of the first and second kind and their derivatives, BESEL, are written in FORTRAN 4. The computer system used was the Hewlett-Packard 21MX M series minicomputer.

```
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   FTH4,L
   #EDACCMBLK, 0>
   PROGRAM RADMI
                desperation of the same of the
   C
                                                                           ROBERT K. SCHNEIDER
                                                                            * THIS PROGRAM EVALUATES THE EIGENVALUE SOLTION FOR THE PADIATED FIELD
                OUTSIDE AN INFINITELY LONG DISLECTRIC CYLINDRICAL SHELL OF INNER
               RADIUS B AND OUTER RADIUS C. THE INCIDENT FIELD HAS AS ITS SOURCE
               AN INFINITE LINE CURRENT CLOSE TO, BUT ENTERNAL TO, THE CYLINDER
   \mathbf{C}
               AND AT AN AMOLE PHI-PRINE EQUAL TO ZERO.
       * A MATRIX EIGENVALUE SCLUTION HAS BEEN FORMULATED LEAVING THE COEFFI-
               CIENTS OF THE FIELD TO BE SOLVED FOR. AN ALGORITHM BY FRESCOTT O.
               CROUT IS USED TO SOLVE FOR THESE COEFFICIENTS.
   C * THE FAR FIELD IS GIVEN BY :
                              Ezon = -jwoFn TIMES THE HANKEL FUNCTION OF THE 2nd KIND
                                                   OF ARGUEMENT KO*RAU AND ORDER h.
                THE TOTAL FIELD IS A SUM ON N OF THE ABOVE.
                                                                                                                               A CONVERGENCE OF THIS
                SUM IS DETERMINED BY THIS PROGRAM. ALSO, SINCE THE ARGUMENT OF THE
               MBOVE HANKEL FUNCTION IS >> m, THE APPROPRIATE ASYMPTOTIC EXPANSION
                IS USED.
       * EPSLN IS A VALUE INPUT BY THE USER FOR USE IN DETERMINING CONVERGENCE.
   C * KO = WAVE NUMBER IN FREE SPACE
   C * K2 = WAVE NUMBER IN DIELECTRIC
                      INTEGER ESTIME
   C
                      REAL KO, K2, MAX, NRMFLD, HPHI, JO
   \mathbf{C}
                      COMPLEX H820A, HNP20A, SUMEZ, A(6,7), F(6), FN(1001), D11, D12,
                                          SUMM, SUMP, SUM, EZON, D5
   C
                      DIMENSION IEUFR(16), U2(10)
   C
                       COMMON /CMBLK/ A,F,ECHWPW(3600),DGRENC,SCRPEZ(3600),
                                                          DBPRPT(3600)
                      DATA PI/3.14159265/
                      DATA XCR/4.875/, YCR/3.875/, RDS/2.748/
        * SET UP CALL FOR INPUT FROM DISK FILE "DATA!"
   C:
```

CALL SPOPH(IBUFR, ISLU)

CALL EXEC(22,1)

DATA IBUFR/2*0,2HDA,2HTA,2H1 ,3*0,221B,7*0/

```
¢
        READVISLU, *> ANOS.C, CUPENT.R, EPSLN, FRED. PERM, DGRENC. EFSLNR,
                      ESTIME, N, ISKIP
  * SET DEFAULT FOR ESTIME
         IF(ESTIME .EQ. 0) ESTIME=500
        ZERO=0.0
  * CALCULATE THE WAVE NUMBERS
         K 0=2, 0*PI*FREQ/3,E8
         K2=KG#SGRT(EPSLNR)
  * COMPUTE ARGUEMENTS FOR BESEL FUNCTION CALLS
         X1=K0#AA
         M2=K0*B
         3*9 対⇒8代
         X4=K2*B
         X5≈K2*€
  * LOOP ESTINE TIMES TO DETERMINE THE EIGENVALUE FR FOR EACH ORDER N.
         K≠0
£:
        DO 100 L=-ESTINE, ESTIME
           K=K+1
           EFSLNN=1.0
           LM1=L-1
           LM1=L
c
             CALL BESEL(LM1, X1, BB, Y, BP, YP)
            HN20A=CMPLX(BB,-Y)
           HNP20A=CMPLX(BP,-YP)
          ĂK1,1)=CMPLX(BB,ZERO)
          A(1,2)=CMPLX(Y,ZERO)
          A(1,3)=(0.,0.)
          A(1,4)=(0.,0.)
          A(1,5)=(0.,0.)
          A(1,6)=-HN20A
          A(1,7)=(0.,0.)
CC
          AK6,10=CMPLX(BP,ZERG)
          AK6,20=CMPLXKYP,ZERG0
          A(6,3)=(0.,0.)
          A(6,4)≈(0.,0.)
          A(6,5)=(0.,0.)
          A(6,6)=-HNP20A
             IF(LM1 .EQ. 0) EPSLNN=0.5
            'EQUMT=(CURENT*EPSLMN)/(PI*AA*KO)
          A(6,7)=CMPLX(EQLMT,ZERO)
C
             CALL BESEL(LM1, X2, BB, Y, BP, YP)
            DUNI =-KORBP
          A(3,5)=CMPLX(-BB,ZERO)
CC
          AK5,50=CMPLX6DUM1,ZERO)
```

C

```
CALL BESELVLM1, M3, BB, Y, BP, YP)
            DUM1=K(tepp
            DUM2=KO*YP
           AK2,10=CMPLXKBB,ZERO0
          AK2,2)=CMPLXKY,ZERO;
CC
           A(4,1)=CMPLDX DUM1, ZERO)
          A(4,2)=CMPLX(DUM2,ZERO)
              CALL BESEL(LM1, X4, BB, Y, BP, YP)
            DUM1=K2*BP
            DUM2=K2*YP
          A(3,1)=(0.,0.)
           A(3,2)=(0.,0.)
          A(3,3)=CMPLX(BB,ZERO)
          AC3,40=CMPLXCY,ZERG0
          A(3,6)=(0.,0.)
          A(3,7)=(0.,0.)
CC
          A(5,1,0=(0.1,0.1)
           A(5,2)=(0.,0.)
             T, TOWCHPLNODUM1, ZERGO
           r 5,10=CMPLX(DUM2,ZERO)
          Ac. = Dec(0.,0.)
          A(5,7)=(0.,0.)
C
             CALL BESEL(LN1, M5, BB, Y, BP, YP)
            DUM1=-K2*BP
            DUM2=-K2+YP
           A(2,30=CMPLX(-BB,ZERO)
           A(2,4)=CMPLX(-Y,2ERG)
          A(2,5)=(0.,6.)
          A(2,6)=(0.,0.)
          A(2,7)=(0.,0.)
CC
          A&4,30=CMPLX(DUM1,ZERO)
          AC4,40=CMPLXCOUM2,ZERGO
          A(4,5)=(0.,0.)
          A(4,6)=(0.,0.)
          A(4,7)=(0.,0.)
  * NOW THAT THE MATRIX A IS FORMED, CALL CLSKY TO SOLVE FOR THE
C
     EIGENVALUES.
           ス=ドナー
          CALL CLSKY(N,M)
C
 * PULL OUT FN FROM ARRAY F
            IFKK .NE. 100 GO TO 17
          DO 19 I=1,6
C
C:
            WRITE(6,18) F(1),L,I
           FORMATCIX, "F= ",1E15.8,2%,E15.8,5%,14,5%,14,7)
18
019
           CONTINUE
           WRITE(6,70)
C
           K = 0
C
17
          FN(L+ESTIME+1)=F(6)
C
           DO 60 M=1,6
```

```
WRITE(6.50) F(M), M, L
             FORMATCIN, "F=",2N,1E15.8,2N,E15.8.5M,14.5M,14)
50
060
              CONTINUE
C:
              WRITE(6,70)
70
             FORMATC1X, 220
C.
100
         CONTINUE
C
          WRITE(1,200)
200
         FORMAT(1X, "FN EIGENVALUES CALCULATED.")
C * CALCULATE THE ECHO WIDTH FER WAVELENGTH RELATIVE TO THE INCIDENT
     FIELD AT THE CENTER OF THE OBSTACLE
C
            SFLDMX=0.0
            TFLDMM=0.0
            IAVNTM=0.0
            IMAX=0
          NTIMES=IFIX(360, ZDGRENC)
         DO 700 I=1,NTIMES
             Ihi = I - i
             PHI=IM1+DGRENC*PI/180.
             HICHVRG= 0
             SUMEZ=\langle 0.,0. \rangle
              SUMM=(0.,0.)
              SUMP=(û.,û.)
         DO 550 J=1, ESTIME
             JM1=J-1
             ARGP=JM1*PI/2.
            D1=SIN(ARGP)
2
           D2=COS(ARGP)
              IF( JM1 .EQ. 0) GO TO 540
             ARGM=-ARGP
3
           D3=SIN(ARGM)
          _D4=COS(ARGM)
SUMM=FN(JM1)*COS(-JM1*PHI)*CMPLX(D3,-D4)
4
5
          SUMP=FN( JM1+ESTIME+1)*COS( JM1*PHI)*CMPLX(61, -D2)
540
С
         SUMEZ=SUMEZ+2.*PI*FREQ*PERM*(SUMM+SUMP)
C
6
          D10=D2*AIMAG(FN(UM1+ESTIME+1))*COS(UM1*PHI)*2.*PI*FREQ*PERM
               IF(D10 .GT. EPSLN) GO TO 550
                NCNVRG=NCHVRG+1
                J2K NCNVRG )= J
               IFCHCHYRG .LT. 10) GO TO 550
                DO 425 L=2,10
                 IF(J2(L) .NE. J2(L-1)+1) G0 T0 427
425
                CONTINUE
                 GO TO 510
427
               NCHVRG=10-L
                DO 426 L=1,10
                  IF(L .GT. NONVRG) GO TO 428
                 J2(L)=J2(10-NCNVRG+L)
                  GO TO 426
428
                 J2(L)=0
426
                CONTINUE
550
               CONTINUE
                WRITE(6,506)
```

```
506
               FORMAT(IM, "TRIED MORE THAN ESTIME TERMS IN SUM. ", /)
051.0
                  WRITE(6,5200 1,0
520
               FORMAT(12), "I=",22, I4,52," U=",22, I4, //)
Ç.
510
                DEKAMI CKAMI .TD. 6 ) FI
               L+MTHVAI=MTHVAI
                IFCISKIP .NE (1) GO TO 530
              ARGCS=((K0*R)-(PIZ4.0))Z(200*PI)
               GC TO 7
530
              ARGOS=(KO*R)-(PI/4.0)
\mathbf{c}
C
              WRITE(6,79) AAGCS
79
           FORMATKIX, "ARGOS= ",E15.8,7)
7
            D1=COS(ARGOS)
C
C
               WRITE(6,77)
77
            FORMATCIX, "GETTING HERE 7", /)
C
સ
            D2=-SINCARGOS)
C
C
               WRITE(6,78)
            FORMAT(1%, "GETTING HERE 8",/)
78
C
            D3=S0RT(2/(P1*K0*R))
            D5=D3*CMPLX(D1,D2)
           EZON=D5*SUMEZ
C
           SCRPEZ(I)=CABS(EZ0N)
C
             IFKSCRPEZ(I) .GT. TFLDMX) TFLDMX=SCRPEZ(I)
C
              ARG=K 0*ABS( AA )
               CALL BESEL(0, ARG, BB, Y, BP, YP)
              JU=BB*BB
              Y0=Y*Y
              D1=3.E8**4.*8.854E-12**2.*8./(FREQ**2.*CURENT**2.*PI**3.)
9
               ARG=K0*AA*COS(PHI)
11
              D2=COS(ARG)
              D3=SIN(ARG)
              D4=2.*PI*FRE0*CURENT/(4.*3.E8**2.*8.854E-12)
              D12=D4+CMPLX(D2,D3)
              D11=SUMEZ+D12
            XMAG=CABS(D11)*CABS(D11)
C
            ECHWPW(I)=D1*XMAGZ(J0+Y0)
C
C
               WRITE(6,1000) ECHWPW(I), PHI
               FORMAT(1X, "ECHWPW=",2X,1E15.8,5X, "PHI=",2X,F7.3,/)
C1000
              IF(ECHWPW(I) .GT. SFLDMX) SFLDMX=ECHWPW(I)
C
700
            CONTINUE
C
                  SCRPEZ(NTIMES+1)=SCRPEZ(1)
C:
              WRITE(6,1200)
1200
            FORMATC 1X, ZZZZZ
```

```
WRITE(1,23)
23
            FORMATO PLOT THE SCATTERED FIELDRE YOR">
             READ(1,12) IANS
              IF(IANS .EQ. 1H ) GO TO 505 IF(IANS .NE. 1HY) GO TO 507
C * PLOT THE ECHO WIDTH PER WAVELINGTH VS HIGLE
C
505
             CALL ECOPT(SFLDMX)
             DO 900 I=1.NTIMES
507
                PHI=(I-1,)+DGRENC
               WRITE(6,800) ECHWPW(I),PHI
C
              FORMATCIX, "ECHWPW=",2%,1815.8,5%, "PHI=",2%,FT.3,/)
800
             CONTINUE
900
              WRITE(1,29)
             FORMATO "PLOT THE TOTAL FIELD?& YON" >
29
              READ(1,12) IANS
             FORMAT(A1)
12
               IF(IANS .EQ. 1H ) GO TO 555
               IF(IANS .NE. 1HY) GO TO 950
555
              WRITE(1,13)
13
             FORMATO "NEW GRID? & YZN")
              READK1,120 IANSS
               IFKIANSS .EQ. 1H ) GO TO 560
IFKIANSS .NE. 1HY) GO TO 565
C
560
             CALL POLAR(0) .
             CALL LABL(0)
C
              WRITE(1.28)
565
             FORNAT( "ENTER PER# FOR DATA . 0" )
28
              READ(1,*) IPHD
              WRITE(25,22) IPHD
22
             FORMATO "SP", 41)
C
95û
             DO 600 I=1,NTIMES+1
                PHI=((I-1)*DGRENC+180.)*PI/180.
               DBPRPT(I)=20.*ALOGT(SCRPEZ(I)/TFLDMX)
                 PHII=(I-1)*DGRENC
                 WRITE(6,33) DBPRPT(1),PH.I.
             FORMATKIN, "GAIN - POWER = ",E15.8," db",5%, "ANGLE = ".
33
                     F7.3,/>
C
                 IF(DBPRPT(I) .LT. -40.) DBPRPT(I)=-40.
               DUMNY=(DBPRPT(I)+40.)/40.
               IX=INT((XCR-DUMMY*COS(PHI)*RDS)*1000.)
             · IY=INT( < YCR-DUMMY*SIN(PHI)*RDS)*1000.)
                 IFCIANS .NE. 1H .AND. IANS .NE. 1HY) GO TO 600
                WRITE(25,24) IX, IY
              FORMATK "PA", 15", "15"; PD")
24
              CONTINUE
600
C:
               WRITE(25,26)
26
               FORMAT("PU")
```

```
CALL LABELS (1)
              DO 940 I=1, NTIMES
                 PHI=(I-1)*DGRENC
               WRITE(6,935) DEPRPT(1),PHI
               FORMATKIX, "POWER GAIN \star ", £15.8," db", 5%. "ANGLE =",
935
                      F7.3," DEGREES",/)
           CONTINUE
940
C
              WRITE(6,70)
0950
               WRITE(6,945) SFLDMX
             FORMATCIX, "THE ECHUPU-MAX = ",E15.8,2/>
945
              WRITE(6,957) TELDNX
C
             FORMATCIX, "THE TOTAL FIELD-MAX" ", E15.8)
957
\mathbf{c}
              WRITE(6,70)
C
              IAVNTH=IAVNTH/NTIMES
\boldsymbol{c}
             WRITE(6,947)
            FORMATCIX, "THE AVERAGE NUMBER OF TERMS IN THE INFINITE SUM")
947
C
             WRITE(6,948) NTIMES
            FORMAT(1X, "FOR ", 15," NUMBER OF ANGLES BETWEEN 0 & 360 IS",/>
948
             WRITE(6,949) IAVNTM
C
949
            FORMATK 1%, I5, "
                            TERMS.")
C
             WRITE(6,70)
Ċ
             WRITE(6,951) IMAM
            FORMAT(1X, "AND, THE MAX NUMBER OF TERMS WAS ", 15, " TERMS.")
951
C
             CALL EXEC(23,5HSMP ,4,ISLU)
£:
              END
              END#
```

```
Y T=00004 IS ON CROCORS USING 00005 BLKS R=0000
  FTH4.L
  #EMACCMBLK, 0)
   SUBROUTINE CLSKY(N,M)
  Contribution in the second of 
                               COMPLEX A(6,7),F(6),
                                                            SUM
   C
                               COMMON /CMBLK/ A,F,ECHWPW(3600),DGRENC.SCRPEZ/3600),
                                                                                     DBPRPT(3600)
   C
                               DATA PI/3.14159265/
   C:
   C * CALCULATE FIRST ROW OF UPPER UNIT TRIANGULAR MATRIX
                               D0 3 3;=2,H
   3
                               AC1, (0)=AC1, (0)ZAC1, (0)
          * CALCULATE OTHER ELEMENTS OF U AND L MATRICES
                               DO 8 I=2,N
                                .t= I
                               DO 5 II=J,N
                                SUM=(0.0,0.0)
                                JMI = J - I
                               DO 4 K=1, JH1
                               SUM=SUM+A(II,K)*A(K,J)
                               ACII, JD=ACII, JD-SUM
                               IP1=I+1
                               DO 7 33=IP1,M
                               SUM=(0.0,0.0)
                                IM4 = I - 1
                               DO 6 K=1, IM1
                               SUM=SUM+A(I,K)*A(K,JJ)
                               A(I, J)A((MU2-(LL)A)=(A(I,I)A)
   3
                               CONTINUE
         * SOLVE FOR F(I) BY BACK SUBSTITUTION
                               F(N)=A(N,N+1)
                               L=H-1
                               DO 10 NN=1,L
                                SUM=(0.0,0.0)
                                1=14-14H
                                IP1=I+1
                               DO 9 J=IP1,H
                                SUM=SUM+A(I,J)*F(J)
    10
                                F(1)=A(1,M)-SUM
                               RETURN
                               END
                               END#
```

```
I T=00004 IS ON CR00039 USING 00006 BLKS R=0000
    FTH4,L
     #EMACCMBLK, 0)
     Control to the control of the contro
                                                    SUBROUTINE ECOPT(MMAX)
     Contraction is a section of the sect
     C
                                         COMPLEX A(6,7),F(6)
     \mathbf{C}
     ε
                                                     COMMON /CMBLK/ A, F, ECHWPW(3600), DGRENC, SCRPEZ(3600),
                                                                                                                                             DBPRPT(3600)
     C
                                                    DATA PIZS.14159265Z
                                                    NX0F=2.#1000
                                                    NY 0P=1.75*1000
     C:
                                                    NMSTP=0.8*1000
                                                   NYSTF=0.5*1000
     \mathfrak{C}
                                                    NXSTPS=9
                                                    NYSTPS=10
                                                      IPEN=1
                                                     WRITE(25,3) IPEN
     Ċ
                                                          NXEP=NX0P+NXSTPS+NXSTP
                                                     WRITEK 25, 1) NXOP, NYOP
                                                     WRITE(25,1) NXEP,NYOP
                                                          WRITE(25,2)
     Ċ
                                                          NYEP=NYOP+NYSTPS*NYSTP
                                                     WRITE(25,1) NXOP,NYOP
                                                     WRITE(25,1) NXOP, NYEP
                                                          WRITE(25,2)
     C:
                                                     DO 100 J=1,HXSTPS
                                                                IX=NXOP+J*NXSTP
                                                                 IY1=NYOP-50
                                                                 IY2=NY0P+50
                                                           WRITE(25,1) IX, IY1
                                                          WRITE(25,1) IX, IY2
                                                                WRITE(25,2)
      100
                                                      CONTINUE
     C
                                                     DO 200 I=1, NYSTPS
                                                                IY=NY0P+I*NYSTP
                                                                 IX1=NX0P-50
                                                                 IX2=NX0P+50
                                                           WRITE(25,1) IX1,IY
                                                          WRITE(25,1) 1%2,1Y
                                                                 WRITE(25,2)
      200
                                               CONTINUE
      C
                                               CALL ECLBL
                                               CALL LAREL(1)
                                               NPTS=IFIX(180./DGRENC)
```

IL T=00003 IS ON CR00039 USING 00015 BLKS R=0000

```
FTR4.L
      SUBROUTINE BESEL(N, X, B, Y, BP, YP)
C
C
      COMPUTE THE BESSEL FUNCTION OF GROER N, N AN INTEGER NOOR=0
      WITH REAL ARGUMENT
C
      ALL EQUATION REFERENCES TO ABRANOWITZ AND STEGUN
      DIMENSION CO(7),C1(7),D0(7),D1(7),E0(7),E1(7),G0(7),G1(7)
      DATA COZ1.0,-2.2499997,1.2656208,-.3163666,.444479E-1,
     *-.39444E-2,.21E-3/
     DATA C17.5,-.56249985, 21093573,-.3954289E-1,.443319E-2,
     *-.31761E-3,.1109E-4/
      DATA DOM.79788456, -.776-6, -.552746-2, -.95126-4, .1372376-2,
     *-.72805E-03,.14476E-03/
     DATA D17.79788456,.156E-5,.1659667E-1,.17105E-3,-.249511E-2,
     *.113653E-02,-.20033E-03/
      DATA E0/-.78539816,-.4166397E-1,-.3954E-4..262573E-2,-.54:25E-3,
     *-.29338-03,.135586-03/
      DATA E1/-2.35619449,.12499612,.565E-4,-.637879E-2,.74348E-3,
     *.79824E-03,-.29166E-03/
     DATA GOZ.3674669,.6055937,-.7435038,.2530012,-.426121E-01,
     *.427916E-02,-.24846E-03/
      DATA G17-.6366198,.2212091,2.168271,-1.316483,.312395,
     *-.400976E-01,.27873E-02/
      DATA PI/3.1415926/
      IFLG=0
      IF (H.LT.0) IFLG=1
      N=TABS(N)
      IF(ABS(X),LT.1,0E-10)G0 TO 150
      IF(ABS(X),GT.3.0)G0 TO 50
      X380=X4X/9.0
      PROD=1.0
      B0=0.0
      B1=0,0
      CUMO=0.0
      CUM1=0.0
      SEE EQUATIONS 9.41 AND 9.44
      DO 5 I=1,7
      B0=B0+C0(I)*PR0D
      B1=B1+C1(I)*PROD
      CUM0=CUM0+GO(I)*PROD
      CUM1=CUN1+G1(I)*PROD
      PROD=PROD*X3SQ
5
      CONTINUE
      B1=B1*X
      XC=2.0*SNGL(DLOG(DBLE(0.5*X)))/PI
      Y0=XC*B0+CUM0
      Y1=XC*B1+CUM1/X
      GO TO 100
      EQS 9,4.3 AND 9.4.6
      THROVX=3.0/X
      PROD=1.0
      F0=0.0
      F1=0.0
      THETA 0=X
      THETA1=X
      DO 55 I=1.7
      F0=F0+D0(I)*PR0D
```

```
F1=F1+D1<1>**PR0D
      THETA0=THETA0+E0(I)+PROD
      THETA: THE JA! + E IX I D*PROD
      PROD=PROD*THROVX
55
      CONTINUE
      SORX=1.0/SNGL(DSORT(DBLE(N)))
      B0=SQRX#F0#SNGLKDCOSKDBLEKTHETA0>>>
      B1=SORN#F1#SNGL(DCOS(DBLE(THETA1)))
      YO=SORX*FO*SNGL(DSIN(DSLE(THETA0)))
      Y1=SQRX*F1*SNGL(DSIN(DBLE(THETA1)))
100
      IF(N-10101,105,110
101
      E≃B0
      BP=-B1
      Y=Y0
      YP=-Y1
      GO TO 200
1.05
      R=R1
      BP=B0-B1/X
      Y=Y1
      YP=Y0-Y1/X
      GO TO 200
      FOR RECURRSIVE DIRECTION COMMENTS SEE SECTION 9.12, P385
C
110
      XN=N
      IFORN.LT.ABSONDOGO TO 130
C
      FOR XK N RECUR DOWNWARD
      BLAST=1.0
      BLASTF=0.0
      J=14+1 (i
      DO 115 I=1,J
      I = J - I
      BNEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST =BREXT
      IF(I.NE.10)G0 T0 115
      BLP=BLASTP
      Z=BNEXT
115
      CONTINUE
      IF(ABS(B0),LT.ABS(B1))G0 T0 117
      CORR=B0/BLASTP
      GO TO 118
117
      CORR=-B1/BHEXT
118
      B=BLP*CORR
      BHMIN1=Z*CORR
      GO TO 140
      FOR XON RECUR UPWARD
C
130
      BLASTP=B0
      BLAST=B1
      DO 135 I=2,N
      \times I = I - 1
      BHEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST=BNEXT
      CONTINUE
135
      B=BLAST
      ENMINI=BLASTP
14 ü
      夏戸=見れ性 I N 1 − X N + 夏 / X
      YEASTP=Y0
      YEAST=Y1
      DO 145 I=2,N
      XI=I-1
```

YHEXT=2.0*XI*YEAST/X-YEASTP YEASTPHYEAST YEAST=YNEXT 145 CONTINUE Y=YLAST YP=YLASTP-XH+Y/X GO TO 200 150 $\mathfrak{g}:\mathfrak{g}=\mathfrak{g}$ RP=0.0 Y'= 0 . 0 YP=0.0 IF(N-1)155,160,200 155 B=1.0 GO TO 200 160 8P=0.5 B=0.5*X 200 IF (IFLG.EQ. 0) RETURN B=(~1)**H*B N=-11 PETURN END END#

T=00004 IS ON CROOCES USING 00005 BLKS R=0000

```
¢
      I. MAIN Program
C:
          1) Reads imputs
C:
0000000000000000000
          2) Calls CELL
           · 출기 취임
             6) NCELLS
          30 Calls CLCRD
             KK (6
             BD YN
          4) Calls ECHOW
             a) WCPHI)/WAVELENGTH
     II. ECHOW (need Ei and En)
          1) Calls FDLTL
             a) En
          2) Calls FLDNC
             a) Ei as a function of PHI
00000
    III. FLDTL (need Emi)
          1) Calls FLONC with PTOBS = 0
             a) Emi
C
C
          2) Sets up matrix, and calls CLSKY
Ċ
             a) En
 >>> Have En and Ei >>> Hawe ECHWPW
000
     IV. MAIN
          5) Calls FLDCT -
Ċ
             a) Es(rauo,phi) <<< Knowing En which is in an array in
                 EMA calculated in II.1
```

```
M T=00004 IS ON CR00039 USING 00020 BLKS P=0000
```

```
FTH4,L
#EMACBLKMM, 0)
Comparison with the production of the contract of the contract
                       PROGRAM RADIM
    C
C
                                                           **************
C
                                                           ROBERT K. SCHNEIDER
                                                           * This program uses the MOMENT NETHOD as presented by JACK RICHMOND
             K"Scattering by a Dielectric Cylinder of Arbitrary Crose Section
             Shape", IEEE APS, Nov 1964, p. 334) to determine the Scattered
O.
            Field from and Echo Width of a dielectric cylindrical shell of
             circular cross section.
     * The dimensions of the scatterer are read from a data file - DATAFL
                     INTEGÉR NCELLS, NPTS, PTOBS, IPHI, MCELLS
C
                    REAL XNN, YNN, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
                                 ECHUPU
C
                    COMPLEX CHN, EINC1, EINC0, EINC2,
                                         ESCAT,
                                        'TAUT, ALMDA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
            2
            3
                                         TAU, VIN, YOUT, OHE, ZERO, TLFLD, AO, A1
Ċ
                    DIMENSION IBUFR(16)
C
                    COMMON VBLKMMV AA, B, C, R, FREQ, PERM, DGRENC, EPSLNR, AN, NCELLS,
                                                           EINC1(360), VIN(1851), ESCAT(360),
                                                           ECHWPW(360), K0, K2, VOUT(1851), TAUC1851),
            2
            3
                                                           EINC2, SCRPEZ(361), DEPRPT(361), A0(1851), A1(1851)
C:
                    EQUIVALENCE (NCELLS, NZ)
C
                    DATA PIZ3.14159265Z
                    DATA MCR/4.875/, YCR/3.875/, RDS/2.748/
                    DATA IBUFR/2*0,2HDA,2HTA,2HFL,3*0,2218,7*0/
C * SET SPOOL FOR INPUT FROM IBUFR THROUGH ISLU
                    CALL SPOPH(IBUFR, ISLU)
                    CALL EXEC(22,1)
                    READ(ISLU,*) AA, B, C, CURENT, R, FREQ, PERM, DGRENC, EPSLNR, NCELLS,
                                                      HLFCEL
         DETERMINE THE CELL STRUCTURE AND # OF CELLS
C
                       id = 0.0
                    CALL CELL(W)
C***
                            IFKHLFCEL .NE. 10 GO TO 50
                       NCELLS=NCELLS/2
```

```
C * DETERMINE THE COORDINATES OF THE CENTERS OF SACH CELL
C50
         CALL CLORD(W)
C * DETERMINE THE ECHO WIDTH PER WAVELENGTH
C
50
         MMAX=0.
        CALL ECHOW(XMAX, W)
C
         NPTS=IFI)X 360, /DGRENC)
C
           WRITE(1,23)
          FORMATO PLOT THE SCATTERED FIELDON YAND)
23
           READ(1,12) IANS
          FORMAT(A1)
12
            IFCIANS .EQ. 1H > GO TO 210
            IFCIANS .NE. 1HY) GO TO 220
C * PLOT ECHO WIDTH PER WAVELENGHT
C
21 û
        CALL ECOPT(XMAX)
C * DETERMINE THE FAR ZONE SCATTERED FIELD AT EACH DGRENC
        CALL FLDCT
220
C * DETERMINE THE INCIDENT FIELD IN THE FAR ZONE
        CALL FLDNC(1,W)
C
        TFLDMX=0.0
        DO 260 I=1, NPTS
          TLFLD=EINCI(I)+ESCAT(I)
         SCRPEZ(I)=CARS(TLFLD)
          #F(SCRPEZ(I) .GT. TFLDMX) TFLDMM=SCRPEZ(I)
260
        CONT INUE
C
          SCRPEZ(NFTS+1)=SCRPEZ(1)
C
         WRITE(1,24)
        FORMAT( "PLOT THE TOTAL FIELD ? Y/N")
24
        READ(1,12) TANS
         IF(IANS .EQ. 1H ) GQ TQ 230
         IF(IANS .NE. 1HY) GO TO 270
C
230
         WRITE(1,25)
25
        FORMATY "NEW GRID?& YZN")
        READ(1,12) TANS
         IFCIANS .EQ. 1H \rightarrow GO TO 240
         IF(IANS .NE. 'HY) GO TO 250
240
        CALL POLAR(0)
        CALL LABL( 0 )
C
250
         WRITE(1,28)
23
        FORMAT("ENTER PEN# FOR DATA.8 ")
        READ(1,*) IPND
         WRITE(25,22) IPHD
```

```
22
        FORMAT("SP", Ii)
        DO 700 I=1, NPTS+1
          PHI=((I-1)*DGRENC+180.)*PI/180.
         DBPRPT(I)=20.*ALOGT(SCRPEZ(I)/TFLDMX)
           IF(DBFRFT(I) .LT. -40.) DBFRFT(I)=-40.
          DUMMY=/DBFRFT(I)+40.0/40.
          IN=INTKCNOR-DUMMY*COSCPHID*RDSD*:000.0
         IY=INT((YCR-DUMMY*SIN(PHI)*RDS)*1000.)
          WRITE(25,29) IX,IY
         FURMAT("PA", IS", "IS"; PD")
29
700
         CONTINUE
          WRITE(25,3;)
         FORMAT("PU")
31
C
270
          WRITE(1,26)
26
         FORMAT( "HARD COPY OF CALCULATIONS? A YZN" >
         READK1,120 TANS
           IF(IANS .EG. IH ) GO TO 800
           IF(IANS .NE. 1HY) GO TO 500
C
300
          WRITE(6,850) TFLDMX
850
         FORMATKIX, "TOTAL FIELD-MAN = ",E15.8,7/)
         DO 870 I=1, NPTS
           PHI=(I-1)*DGRENC
           WRITE(6,860) PHI,ECHUPW(1),DBPRPT(1)
          FORMATKIX, "ANGLE= ",F5.2,5%, "ECHWPW= ",E15.8,5%,
860
                  "DB GAIN= ",E15.8,/)
         CONTINUE
87 Û
C:
27
          WRITE(6,27)
         FORMAT(1X,222)
C
         DO 400 I=1, NPTS
            PHI=(I-1)*DGRENC
            XMAG=CABS((ESCAT(1)))
           WRITE(6,300) XMAG,PHI
300
          FORMAT(1%, "MAGNITUDE ESCAT=",2%,1E15.8,5%, "PHI=",2%,F7.3,/)
400
         CONTINUE
С
500
        CALL EXEC(23,5HSMP ,4,1SLU)
         END
         END#
```

A STANSON AND AND

```
T=00004 IS ON CROCO39 USING 00004 ELKS R=0000
#EMAKBLKMM, 0)
SUBROUTINE CELL(W)
 Ċ
 * THIS SUBROUTINE DETERMINES THE # OF CELLS NEEDED AND THE
C
     DIMENSION OF A CELL TO SEAN THE OBSTACLE.
Ċ.
£.
Ċ
        INTEGER NOELLS, NPTS, PTOES, IPHI, MCELLS
C
        REAL MNN, YNN, EMAGI, U1, U0, K0, K2, Y0, Y1, EmaGH,
            ECHWPW
     1
£:
        COMPLEX CMM, EIHC1, EINCO, EIHC2,
                ESCAT,
                TAUT, ALMDA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
     2
                TAU, VIN, VOUT, ONE, ZERG, AG, A1
C
        DIMENSION IBUFR(16)
Ü
        COMMON /BLKMM/ AA.B.C.R.FREC.PERM.DGRENC.EPELNR.AN.NCELLS.
                       EINC1(360), VIN(1851), ESCAT(360),
                       ECHUPU(360), KO, K2, VOUT(1951), TAUK 1951),
     2
     3
                       EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
C
        EQUIVALENCE (NCELLS, NZ)
C
        DATA PI/3.14159265/
C * THE # OF CELLS FOR THE CIRCULAR DIELECTRIC SHELL SCATTERER IS A
     PARAMETER WHICH IS ASSUMED AT THE INITIATION OF THE PROGRAM AND
C:
     IS READ FROM THE DATA FILE
C * THE WIDTH OF EACH CELL MUST BE LESS THAN OR EQUAL TO
     0.2 * WAVELENGTH / SORT ( EPSLINR )
  * SINCE THE NUMBER OF CELLS IS A KNOWN VALUE AND THE SIZE OF THE
C:
     STRUCTURE IS DEFINED, THE WIDTH OF A 'SQUARE CELL', W, IS EASILY
     DETERMINED TO BE
C
           W=2.#PI#C/NCELLS
C * RADIUS OF CIRCULAR CELL WITH EQUAL AREA AS 'SQUARE CELL', AN, IS
            ROUT≠C
            RIN=C-W
          AN=SQRT((ROUT**2.-RIN**2.)/NCELLS)
          WRITE(6,100) W.AN, NCELLS
0200
        FORMAT(1X, "W=",2X,1E15.9,5X,"AN=",2X,1E15.9,5X,"NCELLS=",
100
               28,14,770
C
        RETURN
         END
         END#
```

```
RD T=00004 IS ON CF00029 USING 00004 BLKS R=0000
```

```
FTH4, L
#EMAK BLKMM, 00
Company to the property of the
                       SUBROUTINE CLORD(W)
C
\mathbf{c}
      * THIS SUBROUTINE CALCULATES THE COORDINATES OF THE CENTER OF
C
              EACH CELL.
C
£:
                        INTEGER NCELLS, NPTS, FTORS, IPHI, MCELLS
C
                       REAL MNH, YMH, EMAGI, J1, J0, K0, K2, Y0, Y1, EMAGM,
                                      ECHWPW
C
                        COMPLEX CMM, EINC1, EINC0, EINC2,
                                               ESCAT,
                                               TAUI, ALMDA, ALPHA, COEF, FRC, C1, C2, V, V1, V2.
              2
               3
                                               TAU, VIN, VOUT, ONE, ZERO, AO, A1
C
                       DIMENSION IBUFR(16)
Č:
                                                                     AA, B, C, R, FRED, PERM, DGRENC, EFSLMR, AM, HCELLS,
                       COMMON ZELKHMZ
               İ
                                                                   EINC1(360), VIN(3702), ESCAT(360), NAM(3702),
              2
                                                                   YNNC3702), ECHWPWC360), KO, K2, VOUTC3702), THUC3702),
              3
                                                                   EINC2, SCRPEZ(361), DBPRPT(361), H0(3702), A1(3702)
ť:
                       EQUIVALENCE (NCELLS,NZ)
Ċ
C
                       DATA PIZ3.14159265Z
C
C
    * RADIUS, OUT TO CENTER OF CELL n
                       RN=0-(U/2.)
C
C
     * INCREMENT ANGLE FOR CELL LOCATIONS
£:
                       THETAN=2.*PIZNCELLS
C
C
                          WRITE(6,50) THETAN
50
                       FORMAT(1X, "THETAN=", 2X, 1E15.9, //)
C * DETERMINE THE CORDINATES OF THE CENTER OF EACH CELL n
                       DO 10 N=1, NCELLS
                             THETA=(N-1)*THETAN
                          XNN( N )=PH*COS( THETA )
                          YNH(N)=RH*SIN(THETA)
C
C:
                             WRITE(6, 100) XHH(H), YNN(H), H
                          FORMATK 1X, "XNN=", 2X, 1E15.9, 5X, "YNN=", 2X, 1E15.9, 5X, "N=", 2X, 14, /)
100
10
                       CONTINUE
                       RETURN
                          END
                          ENDS
```

```
W T=00004 IS ON CR00039 USING 00008 PERS P=0000
  FERRING BLKMM, (1)
  🔃 thromatik delek delek kerik kanak kanak kanak kanak kerik kanak kanak kerik kerik delek kerik                        SUBPOUTINE ECHOW(MMAN, W)
      - 淋淋水淋淋淋淋淋液性性淋漓性神经淋漓体体淋漓体治体系体神经液体体体
  C
      * THIS SUBROUTINE CALCULATES THE ECHO DIDTH PER UNIT WAVELENGHT,
               RELATIVE TO THE INCIDENT FIELD AT THE CENTER OF THE DESTABLE,
               FROM A DIELECTRIC CYLINDRICAL SHELL OF CIACOLAR CLOSS SECTION
               IN THE PRESENCE OF A REDIATING CURRENT FILAMENT.
  C
  C:
  \mathfrak{C}
  C
                       INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
  C
                       REAL XNN, YNN, ENAGI, U1, J0, K0, K2, Y0, Y1, ENAGH,
                                   ECHEPU
                       COMPLEM CHN, EINC1, EINC0, EINC2,
                                           ESCAT,
                                            TSUI, ALMDA, ALFHA, COEF, FAC, C1.C2, V, V1, V2,
               2
                                            TAU, VIN, VOUT, ONE, ZERO, DUMMY4, AO, A1
  C
                       DIMENSION IBUFR(16)
  C
                       CONMON /BLKHM/ AA,B,C,R,FREQ,PERM,DGRENC,EFSLHR,AM,NCELLS,
                                                              EINC1(360), VIN(1851), ESCAT(360),
                                                              ECHWPW(360), KO, K2, VOUTC1851), TAUC1851),
               3
                                                              EINC2, SCRPEZ(361), DBPRPT(361), 40(1851), 41(1851)
  C:
                      EQUIVALENCE (NCELLS, N2)
                       DATA PI/3.14159265/
  C
  C
       * CALL FLOTE TO DETERMINE THE TOTAL FIELD IN THE OBSTACLE
  C
               DUE TO THE INCIDENT FIELD UPON THE OBSTACLE
  ċ
                       CALL FLDTL(W)
  C
       * CALL FLONG TO DETERMINE THE INCIDENT FIELD AT THE CENTER OF
  C
               THE OBSTACLE.
  C
                       CALL FLONC(2,W)
  C
                       NPTS=IFIX(360, /DGRENC)
  C
  C:
                         DO 7 I=1, NPTS
                              WRITE(6,5) EINC2
  5
                            FQRMAT(1X, "ECHOW : EINC2=",2X,1E15.8,2X,E15.8,7)
  C7
                            CONTINUE
       * DETERMINE THE MAGNITUDE SQUARED OF THE INCIDENT FIELD
  C
                         EMAGI=CARS((EINC2))*CARS((EINC2))
  C
                       DUMMY1=K 04 P1**2, *FREQZ(3, E8*EMAGI)
```

```
* LORP MODELLS TIMES FOR THE "SCHTTERED FIELD" IN THE FAR ZONE.
        DO 20 IPHI=1,HPTS
           PHI=KIPHI-1.0:DGRENC*PI/180.
\mathfrak{c}
         DUMMY4=(0.,0.)
C
        RN=C-CUZZ.)
        THETAN=2.*PI/NCELLS
£:
        DO 10 N=1, NCELLS
           THETA=(N-1)*THETAN
            MNN=PN*COSCTHETAD
            YNH=RH*SINCTHETA)
          ARGUI=KO*AN
           CALL BESEL(1, ARGU1, BB, Y, BP, YP)
           J1=BB
          ARGH=K0*(MNN*CCS(PHI)+YNN*SIN(PHI))
          DUMMY2=COS(ARGH)
          DUMNY3=81N(ARGH)
         DUMMY4=DUMMY4+KEFSENR-1.0*VOUTKN0**ANAUT**CHPEXXXDUMMY2.DUMMY30.
10
        CONTINUE
         EMAGN=CABS(DUMMY4)*CABS(DUMMY4)
        ECHMPMC IPHI >= DUMMY1 *EMAGH
CC
         IF(ECHUPW(IPHI) .GT. XNAM) MMAX=ECHUPW(IPHI)
CC
             PHII≔PHI*180./PI
C
         WRITE(6,100) ECHWPW(IPHI),PHII
100
        FORMAT(1M, "ECHWPW=",2M,1E15.9,5M, "PHI=",2M,F7.3,/>
C
20
        CONTINUE
        RETURN
         END
         END$
```

```
L T=00004 IS ON CROOKED USING 00000 BLKS R=0000
 FTH4, L
 TEMAR BLKMM, 0)
 🛴 akin manaka isalisi makalisi kisima arawania a
          SUBROUTINE FLOTL(W)
   i terişk işkişe işkişti, kilge işkişe işkişe işkişe işkişkiş işkişe işkiş kilgi işkiştiş işkişkiş kilgilerişkiş
 Ċ
   * THIS SUBROUTINE CALCULATES THE TOTAL FIELD IN THE GESTACLE
 ť
           INTEGER NOELLS, NPTS, PTOBS, IPHI, MOELLS
 C
          REAL XNN, YNN, Emaci, ut, do, ko, ko, Yo, Yi, Emach,
                ECHUPU
       1
          COMPLEX CMM, EINC1, EINC0, EINC2,
                    ESCAT,
                    TAU1, ALBOA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
       2
       3
                    TAU, VIN, VOUT, ONE, ZERO, AO, A1
 C
          DIMENSION ISUFR(16)
 C
           COMMON ZBEKMMZ AA, B, C, R, FREQ, PERM, DGFENC, EPSENR, AH, NOELLS,
                            EINC1(360), VINC1851), #80AT(360),
                            ECHMPW(360), K0, K2, VOUT(1951), TAU(1951),
       2
       3
                            EINC2, SCRPEZ(361), DBPRPT(361), HOLLISS(), AIR 1951)
 Č.
          EQUIVALENCE (NCELLS, NZ)
 ¢
 C
          DATA PIZ3.14159265Z
 C
   * OBTAIN THE FIELD INCIDENT UPON THE OBSTACLE
 C
           CAÉL FLONC(0,W)
 C
 C
            DO 5 I=1, NCELLS
              WRITE(6,7) EINCO(1),I
            .FORMAT(1X, "FLDTL : EINCO=",2X,1615.8,2%,615.8,5%,"!=",2%,
 7
                     14,/5
 C5
             CONTINUE
 C:
            RH=0-(U/2.)
            THETAN=2, *PI/NCELLS
 C
           DO 30 M=1, NCELLS
 \mathbf{C}
 CO
                  ri= 1
                    THETAN=(M-1)*THETAN
                   XMM=RM*COS(THETAM)
                   YNM=RH#SIRK THETAM)
 CC
 C
           DO 20 N=1, NCELLS
 C * DETERMINE THE WEIGHT Own ON En
```

THETA=(H-1 >) THETAN

AD-A115 B17

AIR FORCE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

THE EFFECT OF RADONE SCATTERING ON ECH ANTENNA PATTERNS.(U)

DEC 81 R K SCHWEIDER

UNCLASSIFIED AFIT/ME/EE/81D-52

NL

END

MC

PAGE

Onc

THE OFFICE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

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THE OFFICE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OF TECH WRIGHT-PATTERSON AF8 OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OH SCHOOL—ETC F/6 17/9

THE OFFICE INST OH SC

```
MANHARY COSCIPHETA )
            CATERT MIES+MR=RMY
          IF(N .NE. 1) 60 TO 10
C
           DUMMY1=K0*AN
           CALL BESEL(1, DUMMY1, BB, Y, BP, YP)
           J1=EB
           Y1 = Y
C
C,
            WRITE(6,8) J1,71,88
ક
           FORMAT(1X, "FLDTE : 01=", 2X, 12+5.8,50; "Y1=", 2X, 1815.8,50;
                   "BB=",2%,1E15.8,/)
Č
         CMN=1.+(EPSLNR-1.0*((PI*K0*AH/2.0*(CMPL%(Y1,010)+1.0
C
          AKM, NO=CMN
             IF(M .NE. 1) GO TO 20
          TAUCH D=CMN
           GO TO 20
C
10
           DUMMY1=PI*KO*AMZ2.
           RMN=SQRT((XHM-XNN)*(XNM-XNN) +
                    CCHRY-MRY >*CHRY-MRY >
           ARGH=K 0*RMH
           ARGU=K0*AN
           CALL BESEL(1, ARGJ, BB, Y, BP, YP)
           J1=88
           CALL BESEL(0, ARGH, BB, Y, BP, YP)
           JO=BB
           Y0=Y
C
         CMN=DUMMY1*(EPSLNR-1.)*J1*CMPLX(Y0,J0)
            IF(N .NE. 1) GO TO 20
          TAUCH >= CMN
C
C
         ACM, NO=CMN
20
        CONTINUE
\boldsymbol{c}
         ACM, H+1 >=-EINCOCH >
030
         CONTINUE
C * NOW THAT THE MATRIX HAS BEEN FORMED, SOLVE FOR EM
        MCELLS=NCELLS+1
C
           WRITE(6,250) MCELLS, NCELLS
250
       FORMAT(1X, "MCELLS=",2X,14,5X, "NCELLS=",2X,14,//)
        DO 400 M=1, NCELLS
C
C
        DO 300 N=1, MCELLS
C
           WRITE(6,350) A(M,H),M,H
       FORMATKIX, "FLDTL : A=",2%,1E15.9,2%;E15.9,5%, "M=",2%,14,
350
               5×,"N=",2×,14,/)
          CONTINUE
C300
С
           WRITE(6,375)
375
         FORMAT(1X, ///)
C4 00
         CONTINUE
C
        DO 600 I=1, NCELLS
C:
C:
           WRITE(6,700) TAU(I),I
         FORMAT(1%, "TAU=",2%,1E15.9,2%,E15.9,5%,I4,/)
700
         CONTINUE
0600
```

```
0 T=00004 IS ON CR00039 USING 00009 SEKS R=0000
FTH4,L
 #EMA(BLKMM, 0)
SUBROUTINE FLDNC(PTORS,W)
   * THIS SUBROUTINE CALCULATES THE INCIDENT FIELD ON THE OBSTACLE,
      AT THE FAR.ZONE POINT, AND/OR AT THE CENTER OF THE OBSTACLE.
 \mathbf{c}
         INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
         REAL XNN, YNH, EMAGI, U1, U0, K0, K2, Y0, Y1, EMAGN,
              ECHWPU
 €
         COMPLEX CHM, EINC1, EINC0, EINC2,
                  ESCAT,
      2
                  TAU1, ALMON, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
               ' TAU, VIH, VOUT, ONE, ZERO, AO, A1
C
         DIMENSION IBUFR(16)
         COMMON /BLKMM/ AA,8,C,R,FREQ,PERM,DGRENC,EPSLNR,AN,NCELLS,
                         EINC1(360), VIN(1851), ESCAT(360),
      2
                         ECHWPW(360), K0, K2, VOUT(1851), TAUK 1851),
                         EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
\boldsymbol{c}
         EQUIVALENCE (NCELLS, HZ)
         DATA PI/3.14159265/
         CURENT=1.0
C
         NPTS=IF1X(360, /DGRENC)
   * WAVE # IN FREE SPACE AND IN THE OBSTACLE
         KO=2.*PI*FREQ/3.E8
         K2=K0*SORT(EPSLNR)
  * EPSLN0 = 8.854E-12
          RN=C-(W/2.)
          THETAN=2.*PI/NCELLS
         DUMMY1=-(K0**2.7(4.*2.*PI*FREG*8.854E-12))*CURENT
     IF OBSERVATION POINT AT PARTICULAR CELL, PTOBS = 0. IF OBSERVATION POINT IN FAR ZONE AT SOME ANGLE PHI, PTOBS = 1. IF
€:
      OBSERVATION POINT AT CENTER OF OBSTACLE, PTOBS = 2.
C
 C
         1F(PTOBS .EQ. 1) GO TO 20
         IF(PTOBS .EQ. 2) GO TO 50
   * DETERMINE THE INCIDENT FIELD ON THE OBSTACLE AT EACH CELL
```

```
Ü
     LOCATION, (Nn, Yn)
C * LOOP MOELLS TIMES FOR INCIDENT FIELD
        DO 10 I=1, NCELLS
              THETA=(I-1)*THETAN
            XNN=RN*COS(THETA)
             YNN=RN+S1N(THETH)
           DUMMY 0=< YIMH-0. D#C YRN-0. D
           ARGH=KO#SORT(KXNN-AA)#CXHN-AA)#DUMMYO)
           CALL BESEL(0, ARGH, BB, Y, BP, YP)
           dú=BB
           Y0=Y
C
          WRITE(6,5) J0,Y0,88
5
         FORMATKIX, "FLDNC : 30=",2%,1E15.8,5%,"Y0=",2%.1E15.8,5%.
                 "BB=",2%,1E15.8,7%
c
         EINCO=DUMMY1*CMPLX(J0,-Y0)
         VINCID=EINCO
C
C:
          WRITE(6,100) EINCO, I, VIN(1)
100
         FORMATCIX, "EINCO=",2%, 1615.9,2%,615.9,5%, "I=",14,
                 5%, "VIN=",2%,1E15.9,2%,E15.9,7)
10
        CONTINUE
         GO TO 40
C
  * DETERMINE THE INCIDENT FIELD AT THE FAR ZONE POINT DUE TO
\mathbf{c}
     THE CURRENT FILAMENT AT RAU PRIME. USE LARGE ARGUEMENT
C
C
     ASYMPTOTIC EXPANSION FOR THE HANKEL FUNCTION.
20
        DO 30 J=1,NPTS
          PHI=(U-1)*DGRENC*PI/180.
           ARGH=K0*(R-AA*COS(PHI))-PI/4.
          D1=COS(ARGH)
          D2=-SINCARGH)
          D3=S0RT(2./(K0*P1*R))
C
         EINCICAD=DUMMY1*D3*CMPLX(D1,D2)
C
          WRITE(6,200) EINC1(J), J
         FORMAT( 1X, "FLDNC : EINC1=",2X,1E15.8,2X,E15.8,5X,"I=",2X,
200
                 14,/)
        CONTINUE
30
£:
         GO TO 40
C
C * DETERMINE THE FIELD INCIDENT AT THE CENTER OF THE OBSTACLE.
C
50
           ARGH=K@*ABSKAA >
           CALL BESEL(6, ARGH, BB, Y, BP, YP)
           J0≈BB
           Ye=Y
C
         EINC2=DUMMY1*CMPLX(J0,-Y0)
\epsilon
4 û
        RETURN
         END
         EHD#
```

```
T T=00004 IS ON CR00079 USING 00010 BLKS R=0000
   FTHH, L
   #ERAK BLKMM, 00
   👸 – inklije inglije i
                                            SUBROUTINE ÉCOPT, XMAX)
    Contract the state of the state
   C * THIS SUBROUTINE PLOTS THE NORMALIZED ECHO WIDTH PER WAYELENGTH
   C:
                             VS. ANGLE PHI ON A LINEAR PLOT.
   c
   C
                                            INTEGER NCELLS, NPTS, PTODS, IPHI, MCELLS
   C
                                            REAL XNN, YNN, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
                                                                    ECHUFW
    C
                                            COMPLEX Crim, ElnCt, ElnCo, ElnC2,
                                                                                    ESCAT,
                                                                                    TAUT, ALMDA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
                             2
                             3
                                                                                    TAU, VIN, VOUT, ONE, ZERO, AO, A1
    C
                                            DIMENSION IBUFR(16)
    C
                                            CONMON /BLKMM/ AA,B,C,R,FREQ,PERM,DGRENC,EPSLNR,AN,HCELLS,
                                                                                                                      EINC1(360), VINC1851), ESCAT(360),
                                                                                                                      ECHWPW(360), K0, K2, VOUT(1851), TAU(1851),
                             2
                             3
                                                                                                                      EINC2, SCRPEZ(361), DBPRPT(361), 40(1851), 41(1851)
   C
                                           EQUIVALENCE (NCELLS, NZ)
   C:
   C
                                            DATA PI/3.14159265/
                                          NX0P=2.*1000
                                            NY 0P=1.75*1000
   C
                                            NXSTP=0.8*1000
                                            NYSTP=0.5*1000
   C
                                            NXSTPS=9
                                           NYSTPS=10
    C
                                            IPEN=1
                                            WRITE(25,3) IPEN
   C
                                                NXEP=NX0P+NXSTPS*NXSTP
                                            WRITE(25,1) NXOP, NYOP
                                            WRITE(25,1) NXEP,NYOP
                                                 WRITE(25,2)
   C
                                                NYEP=NYOP+NYSTPS*NYSTP
                                            WRITE(25,1) NXOP, HYOP
                                            WRITE(25,1) NXOP, NYEP
                                                 WRITE(25,2)
                                            DO 100 J=1,NXSTPS
                                                      IX=HX OP+U*NXSTP
                                                       IY1=MY0P-50
                                                      172=MY09+50
```

WRITE(25,1) IX, IY1

```
WRITE(25,1) 1%,1Y2
           WPITE(25,2)
         CONTINUE
100
C
         DO 200 I=1, HYSTPS
           IY=NYOP+I+NYSTP
           IX1=8X0P-50
           IX2=NX0P+50
          WRITE(25,1) IX1,IY
WRITE(25,1) IX2,IY
WRITE(25,2)
200
        CONTINUE
¢
        CALL ECLBL
        CALL LABEL(1)
C
        NPTS=IFIX(180./DGRENC)
C
        IPEN=3
        WRITE(25,3) IPER
Ċ
        DO 400 IPHI=1,HPTS
           IX=IFIX((TPHI-1.)*DGRENC/20.*NXSTP+2000.)
           IY=IFIXCCECHWPWCIPHIDZXMAXDZ0.1*NYSTP+1750.0
         WRITE(25,1)IN,IY
400
        CONTINUE
C
       WRITE(25,2)
FORMAT("PA",I5","I5,";PD")
FORMAT("PU")
2
        FORMAT("IN; SP", I1)
3
         END
         END*
```

```
T T=00004 18 GN CR00039 USING 00004 BLKS R=0000
  FTN4,L
   #EMA(BLKMM, 0)
   C. with the interference in the contract of th
                         SUBROUTINE FLOCT
        净依依米净排油涂油涂油涂油涂油涂油涂油涂涂涂涂
   C * THIS SUBROUTINE USES THE MOMENT METHOD TO DETERMINE THE SCATTERED
   C
                FIELD FROM SOME DEFINED OBSTACLE
   C
   C.
                          INTEGER NCELLS, NPTS, PTORS, IPHI, NCELLS
   C
                          REAL KNN, YNN, EMAGI, J1, J0, K0, K2, Y0, Y1, EMAGN,
                                       ECHUPU
  C
                          COMPLEX CHM, EINC1, EINC0, EINC2,
                                                 ESCAT,
                                             , TAU1, ALMDA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
                 2
                                                 TAU, VIN, VOUT, ONE, ZERO, DUMMY8, AO, A1
  \epsilon
                         DIMENSION IBUFR(16)
   C
                          COMMON ZBLKMMZ
                                                                     AA,B,C,R,FREG,PERM.DGRENC,EPSLNR,AN,NCELLS,
                                                                    EINC1(360), VIN(1851), ESCAT(360),
                                                                    ECHWPW(360), K0, K2, VOUT(1851), TAU(1851),
                                                                    EINC2, SCRPEZ(361), DEPRPT(361), A0(1851), A1(1851)
  C
                         EQUIVALENCE (NCELLS, NZ)
  \epsilon
  C
                         DATA PI/3.14159265/
  C
       * THE LARGE ARGUEMENT ASYMPTOTIC EXPANSION FOR THE HANKEL FUNCTION
                 IS USED. SEE RICHMOND -----
  \epsilon
: 0
  C * LOOP NPTS TIMES TO OBTAIN THE SCATTERED FIELD AT EACH DIRENC
                         NPTS=1F1X(360,/DGRENC)
  C
                               長れ=0-(も/2.)
                               THETAN=2.*PI/NCELLS
  C
                         DO 20 IPHI=1, NPTS
                               PHI=(IPHI-1)*DGRENC*PI/180.
                               DUMMY1=(KO*R)-(PI/4.)
                               DUMMY2=-COS(DUMMY1)
                               DUMMY3=-SINC DUMMY1)
                               DUMMY4=SQRT(PI*K0*0.5/R)
        * LOOP NCELLS TIMES
                            DUMMY8=(0.,0.)
                         DO 10 H=1, NCELLS
                                  THETA=(N-1 D*THETAN
```

XNN=RN*COS(THETA)
YNN=RN*SIN(THETA)

```
DUMNYS=K (AK SKN*COSKPHI)+YRM*SINKPHI))
          DUMMY6=Cos(butth/5)
          DUMMY7#SIN(DUMMY5)
          ARGUT=K0*Ah
          CALL BESEL(1, ARGUI, BB, Y, BP, YP)
         J1=88
         DUMMYS=DUMMYS+KEPSLNR-1. >*VOUT(N)*AN*J1*CMPLXKDUMMY6,DUMMY7>
10
        CONTINUE .
C
         ESCATCIPHID=DUMMY4*CMPLXCDUMMY3, DUMMY2D+DUMMY8
c
20
C
        CONTINUE
        RETURN
         END
         END#
```

T=00004 IS ON CR00039 USING 00006 SEKS R=0000

```
本巴科岛《巴巴尼科州》,0 )
SUBROUTINE TPLENMM, NHORM, IER)
 C
C * From
C
    "Antenna Theory and Desigh"
      Warren L. Stutzman and Gary A. Thiele
       John Wiley & Sons, New York, 1981
       Appendix 6.7 pp. 579-581
 C * PURPOSE
      TO SOLVE A SYSTEM INVOLVING A TOEPLITZ MATRIX.
                                                  TPLZ REQUIRES
C
      ONLY IN STURAGE LOCATIONS FOR AN N BY N MATRIX.
C * REMARKS
C A toeplitz matrix has the first row equal to the first column.
  All elements along the main diagonal are equal. Any diagonal
  off the main diagonal will have this same property.
C * DESCRIPTION OF PARAMETERS
 . NZ
€
          -ORDER OF MATRIX
          -FIRST ROW OR COLUMN OF THE TOEPLITZ MATRIX (VECTOR
C
   TAU
           LENGTH NZ)
C
          -VECTORS OF LENGTH NZ NEEDED FOR SCRATCH AREA
   A0,A1
          -FOR THE MATRIX EQUATION (2)(1)=(V), VIN IS V.
   VIN
                                                      \langle 2.1.
           AND V MAY BE THOUGHT OF AS GENERALIZED IMPEDANCES,
C
C,
            CURPENTS, AND VOLTAGES, RESPECTIVELY). V IS A NZ BY
            NM MATRIX
C
   MM
          -NUMBER OF COLUMN VECTORS ON THE RIGHT SIDE OF MATRIX
            EQUATION (Z)(I)=(V) (USUALLY 1).
C
          -UPON RETURN THIS IS INFINITE MATRIX NORM OF INVERSE.
   XNORM
   IER
          -ERROR CODE WHICH IS 0 IF NO TROUBLE.
C
C
       INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
C
       REAL XNN, YNN, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
            ECHMPU
    1
       COMPLEX CMM, EINC1, EINC0, EINC2,
              ESCAT,
              TAU1, ALMDA, ALPHA, COSF, FAC, C1, C2, V, V1, V2,
    2
              TAU, VIN, VOUT, ONE, ZERO, AO, A1
    3
C
       DIMENSION IBUFR(16)
C
       COMMON VBLKMM/ AA,B,C,R,FREQ,PERM,DGRENC,EPSLNR,AN,NCELLS,
                     EINC1(360), VIN(1851), ESCRT(360),
    Ž
                     ECHWPW(360),K0,K2,VOUT(1951),TAU(1851),
```

```
3
                         EINC2, SCRPEZ(3610, DBPRPT(3610, A0(18510, A1(18510
Ċ.
        EQUIVALENCE (NCELLS, N2)
C
        DATA ONEXCIEN, NEODZ, ZEROZCOEN, NEODZ
        DATA ORNEZIEUZ, ZRPOZOLEUZ
C:
          WRITE(6,90) NZ,MM
\mathbf{C}
        FORMAT(1%, "HZ=",2%,14,5%, "MM=",2%,14,7)
90
          DO 150 I=1.HZ
        WRITE(6,100) TAUKI), VINCI), I
FORMATCIX, "TPLZ: TAU=",2%,1E15.8,2%,E15.8,5%, "VIN=",2%,1E15.8,
2%,E15.8,5%, "I=",14.7)
C
100
150
          CONTINUE
        N=HZ-1
         IER=0
 * NORMALIZE INPUT MATRIX
          TAUT=TAUCTO
        DO 2000 II=1,N
          TAUCIID=TAUCII+10/TAU1
2000
C * THE FOLLOWING CALCULATES THE ITERATIVE VARIABLES TO OBTAIN
     ACKN) AND ALMDA
 * NOTE : VECTOR ACKID HAS I ELEMENTS AND IS STORED AS ACKI, J),
C
              J=1, H
C:
          ALMDA=ONE-TAUC1 >*TAUC1 >
          A0(1)=-TAU(1)
          1=2
          KK=1-1
   1
          ALPHA=ZERO
        Dũ 2 M=1,KK
         LLE I-M
        ALPHA=ALPHA+AO(M)*TAU(LL)
          ALPHA=-(ALPHA+TAU(I))
           IF(CABS(ALPHA) .EQ. 0.00) GO TO 15
          COEF=ALPHA/ALMDA
          ALMDA=ALMDA-COEF*ALPHA
        DG 3 U=1,7KK
          L=I-J
        A14 J2=A04 J2+C0EF*A04L2
   3
        DO 7 J=1,KK
        CUSTA=CUSOA
          ACKID=COEF
           IF(I .GE. N) GO TO 5
         I = I + 1
          GO TO 1
C * THE FOLLOWING COMPUTES VALUES OF EACH ELEMENT OF THE INVERSE
   5
        NH=(NZ+1)/2
         FAC=ALNDA*TAU1
          XMORM=ZRRO
          HP=HZ+1
        DO 51 I=1,NH
          XHM=ZRRO
```

```
IF(1 .HE, 1) GO TO 52
         育10.10#GH記/EpiC
         Nabi=CaBS(A1(10)
        DO 53 U=2,KZ
         2A3V(1-b)0A=(b)1A
  53
        がおがまくくも シモロンの名音の単作的だ
         G0 T0 54
  52
        MHM=ZRRO.
         dH=I-i
         01=A00 (#F)
         NNFI=NP-I
         02=60(NNFI)
        DO 55 JUH1, N
          J= 44P - JJ
          IMPは=MP-は
          JL=J-1
          A1( 3)=A1( 3L )+( C1*A0( 3L )+C2*A0( INP3 ) )/FAC
  55
        MHM=CABSCATCUDD+MHM
         A10 10=A00 I-10/FA0
         XNM=XNM+CABS(A1(1))
  54
          IFKXNM .GT. NNORM> NNORM=XNM
C * MATRIX MULTIPLY
        DO 56 II=1,66
          ID=(II-1)*NZ
          V≃ZERO
          V1=ZERO
        00 57 J=1,NZ
          HIDJ=ID+J
          V2=VIN(NIDJ)
          V=V+V2*A1(3)
          KNPJ=NP-J
  57
        V1=V1+V2*A1(KNPJ)
         NIDI=ID+I
         V=CIGIN)TUQV
C
          WRITE(6,225) VOUT(HIDI), NIDI
         FORMAT(1X, "TPLZ : VOUT=",2X,1E15.8,2X,E15.8,5X, "NI=",2X,14,/)
225
         KIDHPI=IO+HP-I
  56
        VOUT(KIDNPI)=V1
C
         ·WRITE(6,250) VOUT(KIDNPI), KIDNPI, VOUT(NIDI), NIDI
250
         FORMATK 1%, "TPLZ : VOUT=",2%,1E15.8,2%,E15.8,5%, "KI=",2%.I4,
                 3X, "VOUT=",2X,1E15.8,2X,E15.8,5X, "NI=",2X,14,/)
C:
          WRITE(6,251) VOUT(KIDNPI), KIDNPI
251
         FORMAT(1X,"TPLZ : VOUT=",2X,1E15.8,2X,E15.8,5X,"KI=",2X,14,/)
C
51
        CONTINUE
C
        DO 650 I=1, NCELLS
         WRITE(6,600) VOUT(1),1
C
        FORMATKIX, "TPLZ :: VOUT=",2%,1E15.8,2%,E15.8,5%,"I=",2%,I4,/)
600
        CONTINUE
650
        RETURN
Č:
  15
         WRITE(6,700)
        FORMATKIX, "ERROR HAS OCCUPRED. MATRIX IS STRONGLY NONSINGULAR")
700
         IER=I
C
        RETURN
```

END*

3L T=60003 IS ON CR00039 USING 00015 BEKS R=0000

```
SUBROUTINE BESEL(N, X, B, Y, BP, YP)
C
      COMPUTE THE BESSEL FUNCTION OF GROER N. H AN INTEGER NOOR=0
Ç.
      WITH REAL ARGUMENT
      ALL EQUATION REFERENCES TO ABRAHOWITZ AND STEGUN
      DIMENSION COC75, C1C75, D0C75, D1C75, E0C75, E1C75, G0C75, G1C75
      DATA CG/1.0.-2.2499997,1.2656208,-.3163866..444479E-1,
     *-.39444E-2,.21E-3/
      DATA C17.5,-.56249985,.21093573,-.3954289E-1,.443319E-2,
     *-.31761E-3,.1109E-4/
      DATA DOZ.79788456,-.77E-6,-.55274E-2,-.9512E-4,.137277E-2,
     *-.72805E-03,.14476E-03/
      DATA D17.79788456,.156E-5,.1659667E-1,.17105E-3,-.249511E-2,
     *.115653E-02,-.20033E-03/
      DATA EQ/-.79539816,-.41663976-1,-.39546-4,.262573E-2,-.54125E-3,
     *-.29333E-03,.13550E-03/
      DATA E12-2.35619449,.12499612,.565E-4,-.637879E-2,.74348E-3,
     *.79824E-03,-.29166E-03/
      DATH GOZ.3674669,.6055937,-.7435038,.2530012,-.426121E-01,
     *.427916E-02.-.24846E-03/
      DATA G17-.6366198,.2212091,2.168271,-1.316483,.312395,
     *-.400976E+01,.27873E-02/
      DATA PI/3.1415926/
      IFLG=0
      IF (N.LT.0) IFLG=1
      N=InBS(N)
      IF(ABS(X).LT.1.0E-10)G0 TO 150
      IF(ABS(X).GT.3.0)G0 TO 50
      X350=X*X79.0
      PROD=1.0
      B0=0.0
      \mathbf{E}_i \mathbf{t} = \mathbf{0}_i, \ \mathbf{0}
      CUMC=0.0
      CUM1=0.0
      SEE EQUATIONS 9.41 AND 9.44
      DO 5 I=1,7
      B0=B0+C0(I)*PR0D
      B1=B1+C1(I)*PROD
      CUMO=CUMO+GO(I)*PROD
      CUMI=CUMI+GIKID**PROD
      PROD=PROD*X350
5
      CONTINUE
      B1=B1*X
      MC=2.0*SNGL(DLOG(DBLE(0.5*X)))/PI
      Y0=XC#80+CUM0
      Y1=XC*B1+CUM1/X
      GO TO 100
      EQS 9:4.3 AND 9.4.6
50
      THROVX=3.0/X
      PROD=1.0
      F 0=0.0
      F1=0.0
      THETA 0=X
      THETA1=X
      DO 55 I=1,7
      FO=FO+DO(I)*PROD
```

```
F1=F1+D1(I)*PROD
      THETA 0=THETA 0+E 00 I D*PR GD
      THETA (=THETA) + E1( I )*PROD
      PROD=PROD*THROVX
55
      CONTINUE
      SQRX=1.0/SNGL(DSQRT(DBLE(X)))
      BO=SORX*FO*SNGL(DCOS(DBLE(THETA0)))
      B1=S0EX*F1*SNGL(DC0S(DBLE(THETA1)))
      Y0=S0RX*F0*SNGL(DSIP(DBLE(THETA0)))
      Y1=SORM#F1#SNGL(DSIN(DBLE(THETA:)))
100
      IF(N-10101,105,110
101
      B=80
      BP=-B1
      Y=Y0
      YF=-Y1
      GO TO 200
105
      B=B1
      BP=B0-B1/X
      Y=Y1
      YP=Y0~Y1./X
      GO TO 200
C
      FOR RECURRSIVE DIRECTION COMMENTS SEE SECTION 9.12, P385
110
      38N≔N
      IF(XN.LT.ABS(X))GO TO 130
Ċ
      FOR XK N RECUR DOWNWARD
      BLAST=1.0
      BLASTF=0.0
      J=14+1 0
      DO 115 I=1,J
      XI = J - I
      BNEXT=2.0+XI+BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST =BNEXT
      IF(I.NE.10)G0 TO 115
      BLP=BLASTP
      Z=BNEXT
115
      CONTINUE
      IF(ABS(B0),LT.ABS(B1))G0 TO 117
      CORR=B 0/BLASTP
      GO TO 118
117
      CORR=-B1/BNEXT
      B=BLP*CORR
118
      BNMIN1=Z*CORR
      GO TO 140
C
      FOR XON RECUR UPWARD
130
      BLASTP=B0
      BLAST=B1
      DO 135 I=2,N
      \times I = I - 1
      BNEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST=BNEXT
135
      CONTINUE
      B=BLAST
      BNMIN1=PLASTP
140
      BP=BI#*TR1-XR*BZX
      YEASTP=Y0
      YLAST=Y1
      DO 145 I=2,N
```

 $\times 1 = 1 - 1$

YNEXTHE . 04XI+YLHST/X-YLASTP YEPSTR=YEAST YEASTHYMENT 145 CONTINUE Y=YLAST YP#YEASTP-XN#Y/X GO TO 200 150 B=0.0 BP=0.0 Y=0.0 $YP\!\approx\!0.0$ IF(H-1)155,160,200 155 F=1.0 90 TO 200 160 BP=0.5 B=0.5*X IF (IFLG.EQ.0) RETURN 200 E=(-1)***b*B N=-N RETURN END EHD#

Appendix G. Computer Program for Moment Method

This appendix contains the computer program which implements the moment method solution. This program is a collection of routines written in FORTRAN 4. Each subroutine is self-explanatory; the road map, RDMAP, gives some indication of how the final answers are arrived at. The computer system used was the Hewlett-Packard 27MX series microcomputer.

```
11 T=00004 IS ON CROCO39 USING 00028 BLKS R=0000
```

```
FTHA, L
#EMAKEMBER, 0)
C received the experience of the contract of t
                PROGRAM RADMI
   - 建铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁
C
                                                                    ROBERT K. SCHHEIDER
C
€.
                                                                    C.
    * THIS PROGRAM EVALUATES THE EIGENVALUE SOLTION FOR THE RADIATED FIELD
           OUTSIDE AN INFINITELY LONG DIELECTRIC CYLINGRICAL SHELL OF INNER
C
           RADIUS B AND OUTER RADIUS C. THE INCIDENT FIELD HAS AS ITS COURCE
\epsilon
           AN INFINITE LINE CURRENT CLOSE TO, BUT EXTERNAL TO, THE CYLINDER
           AND AT AN ANGLE PHI-FRIME EQUAL TO ZERO.
C * A MATRIX EIGENVALUE SOLUTION HAS BEEN FORMULATED LEAVING THE COEFFI-
           CIENTS OF THE FIELD TO BE SOLVED FOR. AN ALGORITHM BY PRESCOTT D.
           CROUT IS USED TO SOLVE FOR THESE COEFFICIENTS.
C
e
C
   * THE FAR FIELD IS GIVEN BY :
                         Ezon = -journ TIMES THE HANKEL FUNCTION OF THE 2nd KIND
                                              OF ARGUEMENT KOWRAU AND ORDER A.
           THE TOTAL FIELD IS A SUM ON N OF THE ABOVE.
                                                                                                                         A CONVERGENCE OF THIS
           SUM IS DETERMINED BY THIS PROGRAM. ALSO, SINCE THE ARGUMENT OF THE
C
           ABOVE HANKEL FUNCTION IS >> n, THE APPROPRIATE ASYMPTOTIC EMPANSION
\mathbf{c}
           IS USED.
C * EPSLN IS A VALUE INPUT BY THE USER FOR USE IN DETERMINING CONVERGENCE.
   * KO = WAVE NUMBER IN FREE SPACE
C
C
   * K2 = WAVE NUMBER IN DIELECTRIC
C
C
                  INTEGER ESTIME
C
                  REAL KO, K2, MAX, NRMFLD, NPHI, JO
C
                  COMPLEX HN20A, HNP20A, SUMEZ, A(6,7), F(6), FN(1001), D11, D12,
            1
                                     SUMM, SUMP, SUM, EZGN, D5
C
                  DIMENSION IBUFR(16), J2(10)
C
                  COMMON /CMBLK/ A,F,ECHWPW(3600),DGRENC,SCRPEZ(3600),
                                                     DBPRPT(3600)
C
                  DATA PI/3.14159265/
                  DATA XCR/4.875/,YCR/3.875/,RDS/2.748/
    * SET UP CALL FOR INPUT FROM DISK FILE "DATA1"
                  DATA IBUFR/2*0,2HDA,2HTA,2H1 ,3*0,2218,7*0/
C
                  CALL SPOPN(IBUFR, ISLU)
                  CALL EXEC(22,1)
```

```
C
        READY ISLU, * 7 HAYER, CORENT, ROBESLN, FRED PERM, PGRENT, EPSUNK,
                      ESTINE, N, ISKIP
O * SET DEFAULT FOR ESTIME
         IF(ESTIME .EQ. 0) ESTIME=500
C
        2580=0.0
  * CALCULATE THE WAVE NUMBERS
         K 0=2.0*PI*FREQUE.ES
         K2=K6+SGRTKEPSLNR)
C * COMPUTE ARGUEMENTS FOR BESEL FUNCTION CALLS
         ×1=K0*AA
         >2≃Kú*B
         MB=80*C
         X4=K2#B
         X5=K2*C
C * LOOP ESTIME TIMES TO DETERMINE THE EIGENVALUE FM FOR EACH OPDER M.
         K = 0
        DO 100 L=-ESTIME, ESTIME
           K=K+1
           EPSLNN=1.0
           LM1=L-1
C
           LM1=L
C
             CALL BESEL(LM1, X1, BB, Y, BP, YP)
            HN20A=CMPLX(BB,-Y)
           HNP20A=CMPLX(BP,-YP)
          Å(1,1)=CMPLX(BB,ZERG)
          A(1,2)=CMPLX(Y,ZERO)
          A(1,3)=(0.,0.)
          A(1,4)=(0.,0.)
          A(1,5)=(0.,0.)
          A(1,6)=-HN20A
          A(1,7)=(0.,0.)
CC
          A(6,1)=CMPLX(BP,ZERO)
          A(6,2)=CMPLX(YP,ZERO)
          A(6,3)=(0.,0.)
          A(6,4)=(0.,0.)
          A(6,5)=(0.,0.)
           A(6,6)=-HNP26A
              IF(LM1 .EQ. 0) EPSLNN=0.5
             EOLMT=(CURENT*EPSLHN >/(PI*AA*KO)
           A(6,7)=CMPLX(EQLMT,ZERO)
Ċ
              CALL BESEL(LM1, X2, 88, Y, 8P, YP)
             DUM1=-K@+S∂
           ACS, 50=CMPLXC-BB, ZERO0
CC
           A(5,5)=CMPLX(ĐUM1,ZERO)
¢:
```

```
CALL BESEL(LM1, X3, BB, Y, BP, YP)
             DUM1=K0+EP
             DUM2=KO*YP
           AK2,10=CMPLXKBB,ZERGO
           AK2,20=CMPLNKY,2ERO0
CC
           A(4,1)=CMPLUXCDUM1,ZERO)
           A(4,2)=CMPLM(OUN2,ZERO)
C
              CALL BESSL(LM1, X4, BB, Y, BP, YP)
             DUN1=K2+RP
             DUM2=K2*YP
           A(3,1)=(0.,0.)
           A(3,2)=(0.,0.)
           A(3,3)=CMPLX(BB,ZERO)
           A(3,4)=CMPLX(Y, DERO)
           A(3,6)=(0.,0.)
           A(3,7)=(0.,0.)
CC.
          A(5,1)=(0.,0.)
          A(5,2)⇒(0..0.)
          AC5,30=EMPLNODUM1,ZERQ0
          AK5,40=CMPLXKDUM2,ZERO0
          A(5,6)=(0.,0.)
          A(5,7)=(0.,0.)
              CALL BESELVLM1, X5, BB, Y, BP, YP)
             DUM1 = - K2*8P
             DUM2=-K2+YP
           A(2,3)=CMPLX(-BB,2ERO)
           A(2,4)=CMPLX(-Y,ZERO)
           A(2,5)=(0.,0.)
          A(2,6)=(0.,0.)
           A(2,7)=(0.,0.)
CC
          A#4,3)=CMPLX(DUM1,ZERO)
          A(4,4)=CMPLX(DUM2,ZER0)
          A(4,5)=(0.,0.)
          A(4,6)=(0.,0.)
          A(4,7)=(0.,0.)
C
C * NOW THAT THE MATRIX A IS FORMED, CALL CLSKY TO SOLVE FOR THE
C
     EIGENVALUES.
           M=H+1
          CALL CLSKY(N,M)
  * PULL OUT Fn FROM ARRAY F
C
            IF(K .NE. 10) GO TO 17
\mathfrak{C}
          DO 19 I=1,6
C
             WRITE(6,18) F(1),L,I
18
           FORMAT(1X, "F= ", 1E15.8, 2X, E15.8, 5X, I4, 5X, I4, Z)
C19
           CONTINUE
C
            WRITE(6,70)
           K=0
C
17
          FN(L+ESTIME+1)=F(6)
C
C:
           DO 60 M=1,6
```

```
WRITE(6.50) F(M), M.L
50
            FORMAT: 18, "F=",28.1E15.8.20,E15.8.5M, I4.5M, I4)
06.0
             CONTINUE
C
             WRITE(6,70)
70
            FORMAT(1%, 22)
€.
100
         CONTINUE
C
          WRITE(1,200)
200
         FORMAT(1%, "FN EIGENVALUES CALCULATED.")
£:
C
    CALCULATE THE ECHO WIDTH PER WAVELENGTH RELATIVE TO THE INCIDENT.
     FIELD AT THE CENTER OF THE OBSTACLE
           SFLDMX=0.0
           TFLDMM=0.0
           IAVNTM=0.0
           IMAX=0
          NTIMES=IFIX(360./DGRENC)
         DO 700 1=1, HTIMES
             Ihti = I - i
            PHI=IMI*DGRENC*PI/180.
            MONVRG= 0
             SUMEZ=(0.,0.)
             SUMM=(0.,0.)
             SUMP=(0.,0.)
         DO 550 J=1,ESTIME
             JM1=J-1
            ARGP=JM1*PI/2.
           D1=SIN(ARGP)
           D2=COS(ARGP).
             IF( JM1 .EQ. 0) GO TO 540
             ARGM=-ARGP
3
           D3=SIN(ARGM)
          .D4=COS(ARGM)
5
          SUMM=FN( JM1)*COS(-JM1*PHI)*CMPLX(D3,-D4)
          SUMP=FNC UM1+ESTIME+1 >*COSC UM1*PH1 >*CMPLX(D1, -D2)
540
C
         SUMEZ=SUMEZ+2. *PI*FREQ*PERM*(SUMM+SUMP)
C
          D10=D2*AINAG(FN(JN1+ESTIME+1))*COS(JM1*PHI)*2.*PI*FREG*PERM
               IF(D10 .GT. EPSLN) GO TO 550
               NONVRG=NONVRG+1
                J2(HCNVRG)=J
               IFKHCHYRG .LT. 10) GO TO 550
               DO 425 L=2,10
                 IF(J2(L) .NE. J2(L-1)+1) G0 T0 427
425
                CONTINUE
                 GO TO 510
427
              NCNVRG=10-L
                DO 426 L=1,10
                  IF(L .GT. NONVRG) GO TO 428
                 J2KL)=J2K10-NCNVRG+L)
                  GO TO 426
428
                 J2(L)=0
426
                CONTINUE
550
               CONTINUE
                WRITE(6,506)
```

```
506
                FORMAT(1X, "TRIED MORE THAN ESTIME TERMS IN SUN, ", /)
 0510
                   WRITE(6,520) 1,J
                FORMATC18, "I=",28, I4,58, "J=",28, I4.7)
 520
 510
                 JFKJ .GT. IMAX> IMAX=J
                L+MINVAI=MINVAI
                 IF(ISKIP .NE. 1) GO TO 530
 C:
               ARGCS=((K0*R)-(PI/4,0))/(200*PI)
                GO TO 7
 530
               ARGOS=(KO*R)-(PI/4.0)
 C
 C
               WRITE(6,79) ANGCS
 79
            FORMATCIN, "ARGOS= ",E15.8,/)
 C
 7
              D1=COS(ARGOS)
 C
 C
                WRITE(6,77)
 77
              FORMAT(1X, "GETTING HERE 7",/)
 Ċ
              D2=-SINKARGOS)
 C
 C
                WRITE(6,78)
 78
              FORMAT(1%, "GETTING HERE 8",/)
              DB#SORT(2/XPI*KO*R))
             D5=D3*CMPLX(D1,D2)
            EZ ON=D5*SUMEZ
 C
            SCRPEZ(I)=CABS(EZON)
, ε
              IF(SCRPEZ(I) .GT, TFLDMX) TFLDMX=SCRPEZ(I)
 C
              ARG=K@*ABSCAAD
                CALL BESEL(0, ARG, BB, Y, BP, YP)
               JO=BB*BB
               Y0=Y*Y
              D1=3.E8**4.*8.854E-12**2.*8./(FREQ**2.*CURENT**2.*PI**3.)
               ARG=K0*AA*COS(PHI)
 1 1
              D2=C0S(ARG)
              DB=SIN(ARG)
               D4=2.*P1*FREQ*CURENT.^(4.*3.E8**2.*8.854E-12)
              D12=D4+CMPLX(D2,D3)
              D11=SUMEZ+D12
              XMAG=CABS(D11)*CABS(D11)
 C
              ECHWPW(I)=D1*XMAGZ(J0+Y0)
 C
                WRITE(6,1000) ECHUPUKI), PHI
                FORMAT(1X, "ECHWPW=",2X,1E15.8,5X, "PHI=",2X,F7.3,/)
 C1000
               IF(ECHWPW(I) .GT. SFLDMX) SFLDMX=ECHWPW(I)
 \epsilon
 700
            CONTINUE
 C

    SCRPEZ(NTIMES+1)=SCRPEZ(1)

 C:
              WRITE(6,1200)
 C
 1200
              FORMAT(1X, ZZZZZ)
```

```
C
            URITE(1,23)
           FORMATO "PLOT THE SCATTERED FIELD?8 Y/N">
23
            READ(1,120 TANS
             IFKIANS .EQ. (H ) GO TO 505
             IFKIANS .NE. 1HY) GO TO 507
C * PLOT THE ECHO WIDTH PER WAVELNOTH VS ANGLE
5,05
            CALL ECOPT(SFLDMX)
C
507
            DO 900 I=1,NTIMES
               PHI=(I-1.)*DGRENC
C
               WRITE(6,800) ECHUPW(I), PHI
ទីប៉ប៉
             FORMAT(1X), "ECHMPW=",2X,1E15.8,5X, "PHI=",2X,FT.3,/>
900
             CONTINUE
C
             WRITE(1,29)
            FORMAT( "PLOT THE TOTAL FIELD ?& YZN" >
29
             READ(1,12) TANS
             FORMAT(A1)
               IFKIANS .EQ. 1H > GO TO 555
               IFCIANS .NE. 1HY) GO TO 950
C
555
             WRITE(1,13)
            FORMAT( "NEW GRID?& Y/N" )
13
             READ(1,12) TANSS
               IF(IANSS .EQ. 1H ) GO TO 560
               IFCIANSS .NE. 1HY) GO TO 565
C:
560
            CALL FOLAR(0)
             CALL LABL(0)
C:
             WRITE(1,28)
565
28
             FORMAT( "ENTER PEN# FOR DATA . A." )
             READ(1,*) IPND
             WRITE(25,22) IPND
            FORMAT("SP", It)
22
C
950
            DO 600 I≈1,NTIMES+1
               PHI=<<(I-1)*DGRENC+180.>*PI/180.
               DBPRPT(I)=20.*ALOGT(SCRPEZ(I)/TFLDMX)
                 PHII=(I-1)*DGRENC
                WRITE(6,33> DBPRPT(I),PHII
             FORMATCIX, "GAIN - POWER = ",E15.8," db",5%, "ANGLE = ",
33
                    F7.3,/)
C
                IF(DBPRPT(1) .LT, -40.) DBPRPT(1)=-40.
              DUMMY=CDBPRPTCID+40.0240.
              IN=INT((MCR-DUMMY*COS(PHI)*RDS)*1000.)
              IY=INT((YCR-DUMMY*SIN(PHI)*RDS)*1000.)
                IFCIAMS .NE. 1H .AND. IAMS .NE. 1HY) GO TO 600
               WRITE(25,24) IX, IY
             FORMAT("PA", 15", "I5"; PD")
24
             CONTINUE
600
C
               WRITE(25,26)
26
             FORMAT("PU")
```

```
CALL LABEL(1)
C
             DO 940 I=1, NTIMES
                PH1=CI-10*DGRENO
              WRITE(6,935) DEPRPT(1),PHI
935
              FORMATKIN, "POWER GAIN = ",E15.8," db",5%, "ANGLE =",
                     F7.3," DEGREES",/>
940
            CONTINUE
€:
             WRITE(6,70)
0950
              WRITE(6,945) SFLDMX
            FORMATCIN, "THE ECHWEW-MAX = ",E15.8,7/)
945
             WRITE(6,957) TELDHX
C
957
            FORMAT(1%, "THE TOTAL FIELD-MAX= ",E15.8)
C
             WRITE(6,70)
C
             IAVNIN=IAVNIM/NTIMES
C
            WRITE(6,947)
947
           FORMATCIX, "THE AVERAGE NUMBER OF TERMS IN THE INFINITE SUM")
            WRITE(6,948) NTIMES
C
           FORMATCIX, "FOR ", IS, " NUMBER OF ANGLES BETWEEN 0 & 360 IS", //
948
C:
            WRITE(6,949) IAVNTM
           FORMATCIM, 15, "
949
                           TERMS.")
            WRITE(6,70)
C
            WRITE(6,951) INAX
951
           FORMAT(1X, "AND, THE MAX NUMBER OF TERMS WAS ", 15, " TERMS.")
            CALL EXEC(23,5HSMP ,4,1SLU)
             END
             END#
```

```
Y T=00004 IS ON CR00039 USING 00005 BLKS R=0000
   FTH4.L
   #EMAKEMBLK, 0)
   Control designation of the first of the control of 
                                 SUBROUTINE CLSKY(N, M)
   Contraction of the property of
                                 COMPLEX 466,70,8660,
                                                              SUM
                      1
   C
   C
                                 COMMON ZCMBLKZ A,F,ECHWPW(3600),DGRENC.SCRPEZ(3600),
                       1
                                                                                        DBPRPT(3600)
   C
                                DATA PIZ3.14159265Z
   C:
   C * CALCULATE FIRST ROW OF UPPER UNIT TRIANGULAR MATRIX
   C
                                 D0 3 J=2,M
   3
                                ACI, JOHACI, JOZACI, 10
   C * CALCULATE OTHER ELEMENTS OF U AND L MATRICES
                                D0 8 I=2,N
                                 J= [
                                 DO 5 II=J,N
                                 SUM=(0.0,0.0)
                                  JM1=J-1
                                 DO 4 K=1,UM1
                                 SUM=SUM+ACII,K)*ACK, J)
                                 ACII, J)≃ACII, J)-SUM
                                 IP1=1+1
                                 DO 7 JJ=IP1,M
                                 SUM=(0.0,0.0)
                                 IM+=1-1
                                 DO 6 K=1, IM1
   6
7
                                 SUM=SUM+A(I,K)*A(K,JJ)
                                 A(I, J)>(A(I, JJ)-SUM)/A(I, I)
   8
                                 CONTINUE
   C * SOLVE FOR F(I) BY BACK SUBSTITUTION
                                 F(N)=A(N,N+1)
                                 L=H-1
                                 DO 10 NN=1,L
                                 SUM=(0.0,0.0)
                                  I=M-1414
                                  IP1=I+1
                                 DO 9 J=IP1,N
   9
                                 SUM=SUM+A(I,J)*F(J)
                                 F(I)=A(I,M)-SUM
    10
                                 RETURN
                                 END
```

END*

```
I 1-00004 IS ON CR00039 USING 00006 CLKS R=0000
   FTH4.L
   #EMARICHBLM, 00
   C = (6.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56, 9.56,
                               SUBROUTINE ECOPTAMMAND
  €
                          - COMPLEX A(6,7),F(6)
  C
  C
                                COMMON /CMBLK/ A.F.ECHWPW(3800),DGRENC,SCRPEZ(3800),
                                                                                     DBPRPT(3600)
                     1
   C
                               DATA PIZZ.14159265Z
                               300P=2.*1000
                               NYOP=1.75+1000
   C
                               NNSTP=0.8*1000
                               MYSTP=0.5*1000
   C
                               NXSTPS=9
                               NYSTPS=10
   \mathbf{c}
                                IPEN=1
                                WRITE(25,3) IPEN
   C
                                   NXEP=NX0P+NXSTPS*NXSTP
                                WRITE(25,1) NXOP, HYOP
                                WRITE(25,1) NXEP, NYOP
                                   WRITE(25,2)
                                   HYEP=NYOP+NYSTPS*HYSTP
                                WRITE(25,1) NYOP, NYOP
                                WRITE(25,1) NXOP, NYEP
                                   WRITE(25,2)
   \mathbf{C}
                                DO 100 d=1,NXSTPS
                                       IX=NX0P+J*NXSTP
                                     -IY1=NY0P-50
                                       IY2=NY0P+50
                                    WRITE(25,10 IX,1Y)
                                    WRITE(25,1) IX,1Y2
                                       WRITE(25,2)
    100
                                CONTINUE -
                                DO 200 I=1, NYSTPS
                                       IY=NYOP+I*NYSTP
                                        IX1=HX0P-50
                                       IX2=NX0P+50
                                    WRITE(25,1) IX1,IY
                                    WRITE(25,1) 1%2,1Y
                                       WRITE(25,2)
                            CONTINUE
   200
   C
                            CALL ECLBL
                            CALL LABEL(1)
                            NPTS=IFIX(180./DGRENC)
```

```
C
        IPEN=3
        WRITE(25,3) THEN
C
        DO 400 IPHI=1,HPTS
           IN=IFING(IPHI-1.0+DGRENC/20.*NNSTP+2000.)
           IV=IFIXX (ECHWPUX IPH1)/XMRX0/0.1*MYSTP+1750.>
         WRITE(25,10IN,IY
400
        CONTINUE
C
        WRITE(25,2)
FORMAT("PA",15","15,")PD")
FORMAT("PU")
.
2
3
        FORMATC"IN; SP", II)
         END
         END*
```

12 T=00003 IS ON CRODOSS USING 00015 BLKS R=0000

```
FTN4.L
      SUBROUTINE BESEL(N, X, 8, Y, BP, YP)
\epsilon
C
      COMPUTE THE BESSEL FUNCTION OF GROER N. N AN INTEGER NOOR=0
C
      WITH REAL APGUMENT
C
      ALL EQUATION PEFERENCES TO ABRANOWITZ AND STEGUN
      DIMENSION CO(7),C1(7),D0(7).D1(7),E0(7),E1(7),S0(7),G1(7)
      DATA COZI.0,-2.2499997,1.2656208,-.3163366,.444479E-1,
     *-.39444E-2,.21E-3/
      DATA C17.5,-.58249985,.21093573,-.3054299E-1,.443319E-2,
     4-.31761E-3,.1109E-4/
      DATA DOZ.79788456, -.776-6, -.552746-2, -.95126-4, .1372376-2,
     *-.72805E-03,.14476E-03/
      DATA D17,79789456,.156E-5,.1659667E-1,.17165E-3,-.249511E-2,
     *.f13653E-02,-.20033E-03/
      DATA E0/-.78539016,+.4166397E-1,-.39548-4,.262573E-2,-.54125E-3,
     *-.29333E-03,.13558E-03/
      DATA E1/-2.35619449,,12499612,.565E-4,-.637879E-2,.74348E-3,
     *.79824E-03,-.29166E-03/
      DATH GOV.3674669,.6055937,-.7435038,.2530012,-.426121E-01,
     *.427916E-02,-.24846E-03/
      DATA G17-.6366198,.2212091,2.168271,-1.316483..310395,
     *-.400976E-01,.27873E-02/
      DATA PI/3.1415926/
      IFLG=0
      IF (N.LT.0) IFLG=1
      N=IABS(N)
      IF(ARS(X).LT.1.0E-10)G0 TO 150
      IF(ABS(X),GT.3.0)G0 T0 50
      X350=X*X/9.0
      PROD=1.0
      B0=0.0
      B1=0.0
      อบหต์=0.0
      CUM1 = 0.0
€:
      SEE EQUATIONS 9,41 AND 9,44
      DO 5 I=1,7
      B0=B0+C0(I)*PR0D
      B1=B1+C1( I )*PROD
      CUHO=CUMO+GO(I)*PROD
      CUM1=CUM1+G1(I)*PROD
      PROD=PROD*X3SQ
5
      CONTINUE
      B1=B1*X
      XC=2.0*SNGL(DLOG(DBLE(0.5*X)))/PI
      Y0=XC*B0+CUM0
      Y1=XC*E1+CUN1/X
      GO TO 100
      EQS 9.4.3 AND 9.4.6
      THROVX=3.0/X
50
      PROD=1.0
      Fû=0.0
      F1=0.0
      THETA 0=X
      THETA1=2
      DO 55 I≈1,7
      FO=FO+DOXID#PROD
```

```
F1=F1+D1(I)*PRCD
      THETAO=THETAO+E OUT DIRPROD
      THETA1=THETA1+E101 ) WERED
      PROD=PROD*THROVX
55
      CONTINUE
      SORX#1.0/SNGL(DSORT(DBLE(X)))
      B0=SQRM*F0*SNGL(DCOS(DBLE(THETA0)))
      B1=SQRN#F1#SNGL(DECS(DBLE(THETA1)))
      Y0=SGRXMFOMSHGLKDSIN(DBLEKTHETA0)>)
      Y1=SORX*F1*SNGL(DSIN(DELE(THETA1)))
100
      IFKN-10101,105,110
101
      B=80
      8P=-81
      Y=Y0
      YP=-Y1
      GO TO 200
105
      B=F1
      BP=B0-B1/X
      Y=Y1
      ヤヤーアカーアイアメ
      GO TO 200
      FOR RECURRAIVE DIRECTION COMMENTS SEE SECTION 9.12,9385
110
      MH-H
      IF(XM.LT.ABS(X))GO TO 130
      FOR XX H RECUR DOWNWARD
      BLAST=1.0
      BLASTF=0.0
      J=14+1 Ü
      DO 115 I=1,J
      \times I = J - I
      BHEXT=2,0*XI*BLAST/X-BLASTP
      BLASTF=BLAST
      BLAST =BREXT
      IF(1.NE.10)G0 TO 115
      BLF=BLASTP
      Z=BNEXT
115
      CONTINUE
      IF(ABS(B0).LT.ABS(B1))G0 TO 117
      CORR=BU/ELASTP
      GO TO 118
117
      CORR=-B1/BNEXT
      B=BLP*CORR
113
      BNMIN1=Z*CORR
      GO TO 140
      FOR XON RECUR UPWARD
C
130
      BLASTF=B0
      BLAST=B1
      DO 135 I=2,N
      XI=I-1
      BHEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST=ENEXT
135
      CONTINUE
      B=BLAST
      ENMINI=BLASTP
140
      BP=BH性IN1-米H*BZ米
      YEASTF=Y0
      YEAST=Y1
      DO 145 I=2,N
      XI=I-1
```

YMEXT=2.0*XI*YLAST/X-YLASTP YEASTP=YEAST YEAST= INEXT 145 CONTINUE Y=YLAST YP=YEASTP-XH*Y/X GO TO 200 150 B=0.0 BP=0.0Y=0.0 YP=0.0 IF(N-1)155,160,200 155 B=1.0 GO TO 200 160 BP=0.5 B=0.5*X 200 N=-N RETURN END END#

.P T=00004 IS ON CR00039 USING 00005 BLKS R=0000

```
I. MAIN Program
C
         1) Reads inputs
0000000000000
         2) Calls CELL
             村谷 くま
            6) NCELLS
         3) Calls CLORD
            9) XN
          4) Calls ECHOW
             a) WCPHI)/WAVELENGTH
     II. ECHOW (need Ei and En)
Ĉ
          1> Calls FDLTL
£
             a) En
C
         2) Calls FLDNC
0000
             a) Ei as a function of PHI
    III. FLDTL (need Emi)
£:
          1) Calls FLDNC with PTOBS = 0
             a) Emi
C
Č 📆
         2) Sets up matrix and calls CLSKY
             a) En
C >>> Have En and Ei >>> Have ECHWPW
C:
     IV. MOIN
C:
0000
          5) Calls FLDCT
           a) Estraud, phi) <<< Knowing En which is in an array in
                 EMA calculated in II.1
```

```
M T=00004 IS ON CROCOUS USING 00020 PLKS R=0000
   FTH4.L
   ≢Edia(ELKMM, 0)
    PROGRAM PADMM
    C with the the time of time of time of the time of    C
    C
                                                             ROBERT K. SCHNEIDER
   C:
   C
                                                             C
         * This program uses the MOMENT METHOD at presented by JACK RICHMOND
                ("Scattering by a Dielectric Cylinder of Arbitrary Cross Section
                Shape", IEEE APS, Nov 1964, p. 334) to determine the Scattered
                Field from and Echo Width of a dielectric cylindrical shell of
    C
                circular cross section.
    O * The dimensions of the scatterer are read from a data file - DATHFL
                        INTEGER HOELLS, NPTS, PTOBS, IPHI, MCELLS
    C
                        REAL XNN, YNN, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
                 1
                                     ECHMPW
    €:
                        COMPLEX CMN, EINC1, EINC0, EINC2,
                                            ESCAT.
                2
                                            TAU1, ALMDA, ALPHA, COSF, FAC, C1, C2, V, V1, V2,
                                            TAU, VIN, VOUT, ONE, ZERO, TLFLD, AO, A1
                3
    C
                        DIMENSION IBUFR(16)
    C 📆
                        COMMON /BLKMM/ AA,B,C,R,FREQ,PERM,DGRENC,EPSLNR,AN,NCELLS,
                                                             EINC1(360), VIN(1851), ESCAT(360),
                                                             ECHWPW(360),K0,K2,VOUT((851),TAUC1851),
                2
                3
                                                             EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
    Ċ
                        EQUIVALENCE (NCELLS, NZ)
    C
                        DATA PIZS, 14159265Z
                        DATA MCR/4.875/, YCR/3.875/, RDS/2.748/
                        DATA IBUFR/2*0,2HDA,2HTA,2HFL,3*0,2218,7*0/
        * SET SPOOL FOR INPUT FROM IBUFR THROUGH ISLU
    C
                        CALL SPOPN( IBUFR, ISLU)
                        CALL EXEC(22,1)
     C
                        READKISLU.*) AA, B, C, CURENT, R, FREQ, PERM, DGRENE, EFSLNR, MCELLS,
                                                         HLFCEL
         * DETERMINE THE CELL STRUCTURE AND # OF CELLS
                           W=0.0
                        CALL CELL(W)
    C****
                                IFKHLFCEL .NE. 10 GO TO 50
     C
                           NCELLS=NCELLS/2
     Cara territoria
```

```
C # DETERMINE THE COORDINATES OF THE CENTERS OF EACH CELL
050
         CALL CLEAD(N)
C * DETERMINE THE ECHO WIDTH PER WAVELENGTH
50
         \Sigma MAX=0.
        CALL ECHOW( MMAX, W)
C
         NPTS=IFIX(360./DGRENC)
C
           WRITE(1,23)
          FORMATO PLOT THE SCATTERED FIELDOG YOUN')
23
           READK 1,120 IANS
12
          FORMAT(A1)
            IF(IANS .E0. 1H ) GO TO 210
             IFCIANS INE. 1HY) GO TO 220
C * PLOT ECHO WIDTH PER WAVELENGHT
210
        CALL ECOPT(XMAX)
C * DETERMINE THE FAR ZONE SCATTERED FIELD AT EACH DGRENC
220
        CALL FLDCT
C * DETERMINE THE INCIDENT FIELD IN THE PAR ZONE
        CALL FLDNC(1, W)
Ĉ
        TFLOMX=0.0
\epsilon
        DO 260 I=1,NPTS
          TLFLD=EINC1(I)+ESCAT(I)
         SCRPEZ(I)=CARS(TLFLD)
          "IF(SCRPEZ(I) .GT. TFLDMX) TFLDMX=SCRPEZ(I)
260
        CONTINUE
Č
          SCRPEZ(NPTS+1)=SCRPEZ(1)
C
         WRITE(1,24)
        FORMAT( "PLOT THE TOTAL FIELD ? A Y/N")
24
        READ(1,12) IANS
         IF(IANS .EQ. 1H ) GO TO 230
         IF(IANS .NE. 1HY) GO TO 270
C
230
         WRITE(1,25)
        FORMATO "NEW GRID?& YZN" >
25
        READ(1,12) IANS
         IFCIANS .EQ. 1H > GO TO 240
         IF(IANS .NE. 1HY) GO TO 250
240
        CALL POLAR(0)
        CALL LARL(0)
C
250
         WRITE(1,28)
        FORMAT( "ENTER PEN# FOR DATA. & ")
23
        READ(1,*) IFND...
         WRITE(25,22) IPND
```

```
20
        FORMAT("SP", I1)
        DO 700 I=1, NPTS+1
         ·PHI=<<<!-- i >= DGRENC+180.>*PI/180.
         DSPRET(I)=20.*ALOGT(SCRFEZ(I)/TFLDMX)
          IF(DEPRET(I) .LT. -40.) DEPRET(I)=-40.
          DUMMY=(OBPRET(1)+40.0/40.
         IN=INT((MCR-DUMMY*COS(PHI)*RDS)*1000.)
         IY=INT((YCR-DUMMY*SIN(PHI)*RDS)*1000.)
          WRITE(25,29) 1X,1Y
         FURNAT("PA",15","15";PD")
29
700
         CONTINUE
          WRITE(25,31)
         FORMATC "PU" >
31
C
270
          WRITE(1,26)
         FORMAT( "HARD COPY OF CALCULATIONS ? & YZN" >
26
         READ(1,12) IANS
          IFCIANS .EQ. (H ) GO TO 800
          IF(IANS .NE. 1HY) GO TO 500
C
800
          WRITE(6,850) TELDMX
850
         FORMAT(1%, "TOTAL FIELD-MAX = ",E15.8,2/)
C
         DO 870 I=1, HPTS
           PHI=(I-1)*DGRENC
           WRITE(6,860) PHI,ECHWPW(I),DBPRPT(I)
          FORMATY 1%, "ANGLE= ",FS.2,5%, "ECHWPW= ",E15.8,5%,
360
                 "DB GAIN= ",E15.8,/)
         CONTINUE
37ú
C
          WRITE(6,27)
27
         FORMAT(1X, ZZZ)
         DO 400 I=1, HPTS
          . PHI=(I-1)*DGRENC
            XMAG=CABS((ESCAT(I)))
           WRITE(6,300) XMAG, PHI
300
          FORMATKIN, "MAGNITUDE ESCAT=",2X,1E15.8,5%, "PHI=",2%,F7.3,/)
400
         CONTINUE
C
500
        CALL EXECK 23,5HSMP ,4,1SLU)
         END
         END#
```

```
T=00004 IS ON CROCOBS USING 00004 BLKS R=0000
FTH4, L
#EMACBLKMM, 00
Control of the Anterior of the
                    SUBROUTINE CELL(W)
     碘橡油铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁
C
    * THIS SUBROUTINE DETERMINES THE # OF CELLS NEEDED AND THE
            DIMENSION OF A CELL TO SPAN THE OBSTACLE.
C
C
C
                    INTEGER NCELLS, NPTS, FTORS, IPHI, MCELLS
C
                    REAL XRN, YEN, EMAGI, Ut, JO, KO, K2, YO, Y1, EMAGR,
                                ECHUPU
             1
C
                    COMPLEX CMM.EINC1.EINC0.EINC2.
                                        ESCAT,
                                         TAUT, ALMDA. ALPHA, COEF, FAC, C1, C2, V, V1, V2,
            2
                                        TAU, VIN, VOUT, ONE, ZERO, AO, A1
C
                    DIMENSION IBUFF(16)
C
                    COMMON VBLKMMV AA, B, C, R, FREC, PERM, DGRENC, EPSLAR, AN, NCELLS,
                                                          EINC1(360), VIN(1851), ESCAT(360),
                                                          ECHWPW(360),K0,K2,VOUT(1951),Tack 1851),
            2
            3
                                                          EINC2, SCRPEZ(361), DEPRPT(361), A0(1851), A1(1851)
C
                    EQUIVALENCE (NCELLS, NZ)
C
                    DATA PIZ3.14159265Z
         THE # OF CELLS FOR THE CIRCULAR DIELECTRIC SHELL SCHITTERER IS A
C
             PARAMETER WHICH IS ASSUMED AT THE INITIATION OF THE PROGRAM AND
             IS READ FROM THE DATA FILE
C
    * THE WIDTH OF EACH CELL MUST BE LESS THAN OR EQUAL TO
C
             0.2 * WAVELENGTH / SORT ( EPSLAR )
C
    * SINCE THE NUMBER OF CELLS IS A KNOWN VALUE AND THE SIZE OF THE
             STRUCTURE IS DEFINED, THE WIDTH OF A "SQUARE CELL", N, IS EASILY
C
C
             DETERMINED TO BE
C
                            W=2.*PI*C/NCELLS
C * RADIUS OF CIRCULAR CELL WITH EQUAL AREA AS 'SQUÂRE CELL', AN, IS
                              ROUT=C
                              RIN=C-W
                         AN=SQRT((ROUT**2,-RIN**2,)/NCELLS)
0200
                         WRITE(6,100) W, AN, NCELLS
                    FORMATCIX, "W=",2X,1E15.9,5X,"AN=",2X,1E15.9,5X,"NCELLS=",
100
                                      28,14,223
                    RETURN
                       END
                       END*
```

RD T=00004 IC ON CROSSSS USING 00004 BLKS R=0000

```
#EMAKBLKMM, 03
SUBROUTINE CLORINGUE
 C
C
 * THIS SUBROUTINE CALCULATES THE COORDINATES OF THE CENTER OF
C
     EACH CELL.
C
C
        INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
C
        REAL XNN, YNH, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
             ECHMPM
C
        COMPLEX CMN.EINC1, EINC0, EINC2,
     2
                TAUT, ALMDA, ALPHA, COEF, FAC, C1, C2.V, V1, V2,
                TAU, VIH, VOUT, ONE, ZERO, AO, A1
C
        DIMENSION IBUFR(16)
C
        COMMON VBLKMMV AA, B, C, R, FREQ, PERM, DGRENC, EFSLING, AN, HOELLS,
                       EINC1(360), VIN(3702), ESCAT(360), NAMA 3702),
     2
                       YNN(3702), ECHWPW(360).kg, K2, VOUT(3702), TAU(3702),
                       EINC2, SCRPEZ(361), DBPPPT(361), 40(3702), 41(3702)
٤:
        EQUIVALENCE (NCELLS, NZ)
C
C 📆
C:
        DATA PI/3.14159265/
C * RADIUS OUT TO CENTER OF CELL N
Ç
        RN=0-(W/2,)
 * INCREMENT ANGLE FOR CELL LOCATIONS
        THETAN=2.*PI/NCELLS
C
C
         WRITE(6,50) THETAN
50
        FORMAT(1X, "THETAN=", 2X, 1E15.9, 2/)
C
 * DETERMINE THE CORDINATES OF THE CENTER OF EACH CELL n
        DO 10 N=1, NCELLS
          THETA=(N-1)*THETAH
         XNN(H)=RH*COS(THETA)
         YNNCH DERH#SINCTHETA )
c
C
          WRITE(6,100) XNN(N), YNN(N), N
100
         FORMATK 1X, "XNN=", 2X, 1E15.9, 5X, "YNN=", 2X, 1E15.9, 5X, "N=", 2X, 14, /)
10
        CONTINUE
        RETURN
         END
         END#
```

```
FTH4, L
#EMARBLEMMI, 0)
  "快快"和滚滚滚响中说话,我这根像谁敢的我说话,你说话,我就会说我像像像像像像像像像
        SUBFOUTINE ECHOW(MMM, W)
  - 嫩班市咖啡说《水水本主法物油物物水油法体水油油水水油油油油油油油
 * THIS SUBPOUTINE CALCULATES THE ECHO WIDTH PER UNIT WAVELENGHT.
     RELATIVE TO THE INCIDENT FIELD AT THE CENTER OF THE DESTACLE,
     FROM A DIELECTRIC CYLINDRICAL SHELL OF CIRCULAR CAOSA SECTION
     IN THE PRESENCE OF A RADIATING CURRNT FILAMENT.
C
\boldsymbol{c}
         INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
\mathbf{c}
         REAL XNN, YNN, EMAGI, 31, 30, KO, K2, YO, YI, EMAGH,
              ECHMPLI
C
         COMPLEX CHR.EINC1, EINCO, EINC2,
                 ESCAT,
                 THUI, ALMDA, ALPHA, COSF, FAC, C1, C2, V, V1, V2,
                 TAU, VIN, VOUT, ONE, ZERO, DUMMY4, AU, A1
     3
Ū
         DIMENSION IBUFR(16)
C
         COMMON /BLKMM/ AA,B,C,R,FREQ,PERM,DGRENC,EFSLMR.AM,NCELLS,
                         EINC1(360), VIN(1851), ESCAT(360),
                         ECHWPW(360), K0, K2, VOUT(1851), TAU(1851),
     2
     3
                         EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
C
         EQUIVALENCE (NCELLS, N2)
C:
€:
         DAȚA PI/3.14159265/
C
C * CALL FLOTE TO DETERMINE THE TOTAL FIELD IN THE OBSTACLE
     DUE TO THE INCIDENT FIELD UPON THE OBSTACLE
C
         CALL FLDTL(W)
C * CALL FLONG TO DETERMINE THE INCIDENT FIELD AT THE CENTER OF
     THE OBSTACLE.
C:
\boldsymbol{c}
         CALL FLDNC(2,W)
C
         NPTS=1F1X(360,/DGRENC)
          DO 7 I=1,NPTS
            WRITE(6,5) EINC2
5
           FORMAT(1X, "ECHOW : EINC2=",2X,1E(5.8,2X,E(5.8,7)
C7
           CONTINUE
  * DETERMINE THE MAGNITUDE SQUARED OF THE INCIDENT FIELD
          EMAGI=CABS((EINC2))*CABS((EINC2))
C:
         DUMMY1=KO*PI**2:*FREQZY3.E8*EMAGI>
```

w 7=00004 is on 0900039 USING 00008 BLHS R=0000

```
C * LOOP MICELLS TIMES FOR THE "SCATTERED FIELD" IN THE FAR ZONE.
        DG 20 IPHI=1,8978
           PHI=(1PHI-1.)*DGRENO*PI/180.
         DUMMY4=(0.,0.)
        RM=0-(W/2.)
        THETAN=2.*PI/NCELLS
        DO 10 N=1, NOELLS
            THETA=(N-1)*THETAM
             XMM=PN*COS(THETA)
             YNN=RN*SINCTHETA)
           ARCJ1=K0*AN
           CALL BESEL(1, ARGU1, BB, Y, BP, YP)
           J1=BB
           ARGH=K0*(MMN*COS(PHI)+YMN*SIN(PHI))
           DUMMY2=COS(ARGH)
          DUMMY3=SINCARGH)
          DUMMY4=DUMMY4+< EPSLNR-1. >*YOUT< N >*AN* J1*CMPLY* DUMMY2, DUMMY3> .
10
        CONTINUE
C
         EMAGN=CASS: DUMMY4 )*CABS: (DUMMY4)
C
        ECHWPWC IPHI >= DUMMY 1 * EMAGH
CC
          IF(ECHUPUK IPHI) .GT. MMAX) MMAX=ECHUPUK IPHI)
\epsilon c
C
              PHII=PHI#180.7PI
C
C
         WRITE(6,100) ECHWPW(IPHI), PHII
100
        FORMAT(1X, "ECHWPW=",2X,1E15.9,5X, "PHI=",2X,F7.3,/)
C
20
        CONTINUE
        RETURN
         END
         END*
```

```
L T=00004 IS ON CR00039 USING 00008 BLKS R=0000
  FTH4, L
  #EMAK BLKMM, 0)
   SUBPOUTINE FLDTL(W)
         the foreign the specific property that the specific property the specific property that the specific p
    C
         * THIS SUBROUTINE CALCULATES THE TOTAL FIELD IN THE OBSTACLE
    C
   C
                            INTEGER NCELLS, NPTS, RTOBS, IPHI, MCELLS
   C
                            REAL XHM, YMM, EMAGI, 31, 30, KO, K2, Y0, Y1, EMAGM,
                                           ECHUPU
    C
                            COMPLEX CMH, EINC1, EINCO, EINC2,
                                                    ESCAT,
                                                    TAUT, ALMDA, ALPHA, COEF, FAC, C1, C2, V, VI, V2,
                                                    TAU, VIN, VOUT, OME, ZERO, AO, A1
                   3
    C
                            DIMENSION IBUFR(16)
    C
                            COMMON ZBEKNMZ AA, B, C, R, FRED, PERM, DSRENC, EFSENR, AN, NOSELES,
                                                                         EINC1(360), VINC1851). ESCAT(360),
                                                                         ECHMPUR 360), KO, K2, VOUT( 1951), TAUK 1951),
                   3.
                                                                         EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
   C
                            EQUIVALENCE (NCELLS, NZ)
   C
   C
                            DATA PIZ3.14159265Z
               OBTAIN THE FIELD INCIDENT UPON THE OBSTACLE
                            CALL FLONC( 0, W)
                               DO 5 I=1, NCELLS
    C
                                    WRITE(6,7) EINCO(1),I
    C
                                  FORMAT(1X, "FLDTL : EINCO=",2X,1E15.8,2X,E15.8,5X,"I=",2X,
                                                       14,/)
    C5
                                  CONTINUE
                               PN=C-(U/2.)
                               THETAN=2.*PI/NCELLS
                            DO 30 M=1, NCELLS
    CC
                                              M= 1
                                                    THETAM=(M-1)*THETAN
                                                 XNM=RM*COS(THETAM)
                                                 YNM=RN#SINCTHETAM)
    CC
                            DO 20 N=1, NCELLS
    C * DETERMINE THE WEIGHT Com ON En
                                        THETA=(N-1)*THETAN
```

```
MANERILL COST THETAD
            CATERINATE MARKET
         IFKN .NE. 10 GO TO 10
C
          DUMMY1=110*AB
            CALL BESEL(1, DUMMY1, BB, Y, BP, YP)
           J1=BB
           Y'1 = Y'
\mathbf{c}
C
            WRITE(6,8) Ut, Yt, 89
           FORMATKIN, "FLOTE : 01=",2%.1015.8,5%, "Y1=1,2%,1015.8,5%,
ક
                  "BB=",2%,1E15.8,7%
C
         CMN=1.4(EPSENR-1, 0*(CPI*KO*ANZ2.0*CCMPEXC11, 0100+1.0
Č:
         ACM, NO=CHIN
             IF(M .NE. 1) GO TO 20
         TAUCH DECHIN
           GO TO 20
C
10
           DUMMY1=FI-KO*ADZ2.
           * CHM-SQRTC(XHM-XHN)*(XHM-XNN) +
                    C CMM-LAMA SAC MM-LAMA S
           ARGH=K 04RbN
           ARGU=KONAN
           CALL BESEL(1, ARGJ, BB, Y, BP, YP)
           J1=88
           CALL BESEL(0, ARGH, BB, Y, BP, YP)
           Jú≈BB
           Y 0=Y
C
         CMN=DUMMY1*(EPSEMR-1.)*J1*CMPLX(Y0,J0)
C
            IF(N .NE. 1) GO TO 20
         TAUCH DECMIN
C
         ACM, NO=CMH
20
        CONTINUE
ũ.
         A(M,N+1)=-EINCOCM)
030
         CONTINUE
C
C * NOW THAT THE MATRIX HAS BEEN FORNED, SOLVE FOR EN
        MCELLS=NCELLS+1
C
           WRITE(6,250) MCELLS, NCELLS
250
       FORMAT(1X, "MCELLS=",2X,14,5X, "NCELLS=",2X,14,//)
€:
        DO 400 M=1, NCELLS
C
C
        DO 300 N=1, MCELLS
C
           WRITE(6,350) A(M,M),M,M
       FORMATKIX, "FEDTE : A=",2%,1E15.9,2%,E15.9,5%, "M=",2%,14,
350
               5X,"N=",2X,14,/)
0300
         CONTINUE
ũ
           WRITE(6,375)
         FORMAT( 1X, 272)
375
0400
         CONTINUE
C:
        DO 600 I=1, NOELLS
C
           WRITE(6,700) TAUKI),I
C
700
         FORMAT(1X,"TAU;",2X,1E15.9,2M,E15.9,5X,14,7)
C600
         CONTINUE
```

```
2 T=00004 IS ON CR00039 USING 00009 BLKS R=0000
 FTH4.L
  #EMACEL KMM, 00
  C. Harris of a skir down to be represented by the skir of the skir
                         SUBROUTING FLDNC(PTOBS,W)
  C * THIS SUBROUTINE CALCULATES THE INCIDENT FIELD ON THE OSSTACLE,
               AT THE FAR ZONE POINT, AND/OR AT THE CENTER OF THE OSSTACLE.
  C
  C
                       INTEGER MOELLS, NPTS, PTOBS, IPHI, MOELLS
  C
                       REAL XMM, YNH, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
               1
                                    ECHUPU
  C
                       COMPLEX CMM, EINC1, EINC0, EINC2,
                                            ESCAT.
                                            TAUT.ALMON, ALPHA, COEF, PAC, C1, C2, V, V1, V2,
               2
               3
                                            TAU, VIN, VOUT, ONE, ZERO, AO, At
  \mathbf{c}
                       DIMENSION IBUFR(16)
                       COMMON ZBEKMMZ AA,B,C,R,FREG,PERM,DGRENG,EPSENR,AN,NCELLS,
                                                               EINC1(360), VIN(1851), ESCAT(360),
                                                               ECHWPW(360), K0, K2, VOUT(1851), TRUC1851),
               2
                                                               EINC2, SCRPEZ(361), DEPRPT(361), A0(1851), A1(1851)
               3
  C:
                       EQUIVALENCE (NCELLS, NZ)
  £.
  \epsilon
     ••
  \boldsymbol{c}
                       DATA PIZ3.14159265Z
 C
                       CURENT=1.0
  C
                       NPTS=IFIX(360, /DGRENC)
  C
  C * WAVE # IN FREE SPACE AND IN THE OBSTACLE
                       K0=2.*P1*FREQ/3.E8
                       K2=K0*SQRT(EPSLNR)
  C * EPSLN0 = 8.854E-12
                         RN=0-(W/2.)
                         THETAN=2.*PI/NCELLS
  C
                       DUMMY1=-(K0**2.7(4.*2.*PI*FREG*8.854E-12))*CURENT
       * IF OBSERVATION POINT AT PARTICULAR CELL, PTORS = 0. IF OBSER-
               VATION POINT IN FAR ZONE AT SOME ARGLE PHI, PTOBS = 1.
               OBSERVATION POINT AT CENTER OF OBSTACLE, PTOBS = 2.
  C
  C
                       IF(PTOBS .EQ. 1) GO TO 20
  C
                       IF(PTOBS .EQ. 2) GO TO 50
       * DETERMINE THE INCIDENT FIELD ON THE OBSTACLE AT EACH CELL
```

()

```
C.
     LOCATION, (Nn, Yn)
C * LOOP MCELLS TIMES FOR INCIDENT FIELD
        DO 10 I=1,NCELLS
              THETA=(I=1)*THETAN
             NNN=RN*COS(THETA)
             YERRERNASIN(TRETH)
           DUMMY OF CYRIS- 6. 280 YRN- 6. 2
           ARGH=K0#S0RT< ( MRN-HA )#< MRH-AA )#DURN76 >
           CALL BESELK C, ARGH, 68, Y, 6P, YP)
           J0=88
           Y'0=Y
C
C
           WRITE(6,5) J0,Y0,88
5
         FORMATK 1%, "FLDNC : 30=",2%,1E15.8,5%, "10=",2%,1E15.8,5%,
                 "BB=",2%,1615.8,7)
\mathbf{c}
         EINCO=DUMMY1*CMPLX(J0,-Y0)
         VINCID=EINCO
C
C:
          WRITE(6,100) EINCO, I.VINCI)
100
         FORMAT(1X, "EINCO=", 2X, 1E15.9, 2X, E15.9, 5X, "I=", I4,
                 5%, "VIN=",2%,1E15.9,2%,E15.9,./)
        CONTINUE
10
         GO TO 40
Ū
C
 * DETERMINE THE INCIDENT FIELD AT THE FAR ZONE POINT DUE TO
     THE CURRENT FILAMENT AT RAU PRINE. USE LAFGE ARGUEMENT
C
     ASYMPTOTIC EXPANSION FOR THE HANKEL FUNCTION.
C
20
        DG 30 J=1,NPTS
          PHI=(J-1)*DGRENC*PI/180.
           ARGH=K0*(R-AA*COS(PHI))-PI/4.
          D1=COS(ARGH)
          ₱2=-SIN(ARGH)
          D3=SQRT(2./(K0*PI*R))
C
         EINC1(J)=DUMMY1*03*CMPLX(D1,D2)
          WRITE(6,200) EINC1(J), J
C
200
         FORMAT(1X, "FLDNC : EINC1=",2X,1E15.8,2X,E15.8,5X,"I=",2X,
                 14,75
30
        CONTINUE
C
         GO TO 40
C * DETERMINE THE FIELD INCIDENT AT THE CENTER OF THE OBSTACLE.
C
50
          ARCH=KO+ABS(AA)
           CALL BESEL(0, ARGH, BB, Y, BP, YP)
           JO=BB
           ሦወ≔ሦ
C
         EINC2=DUMMY1*CMPLX(J0,-Y0)
C:
4 ü
        RETURN
         END
         END*
```

```
T T=00004 IS ON CROODES USING 00010 BLKS R=0000
FTHI L
 TETRAK BLKMM, 0)
 (2) 法律法律律律法律法律法律律律法院未必法律法律法院法院法院法院法院
         SUBROUTINE ECOPT, XMAZ)
 (2) 通用中部中部的影響等等級等級等等等等等等等等等等等等等等等等。
 Ċ
  * THIS SUBROUTINE PLOTS THE NORMALIZED ECHO WIDTH PER WAVELENGTH
 \boldsymbol{c}
      VS. ANGLE PHI ON A LINEAR PLOT.
 ¢
 C
         INTEGER NCELLS, NPTS, PTGBS, IPHI, nCELLS
 Ċ
         REAL XNN, YNN, EMAGI, JI, JO, KO, K2, YO, YI, EMAGN,
               ECHWPW
 C
         COMPLEX CMN, EINC1, EINC0, EINC2,
                  ESCAT,
                  TAUL, ALMOA, ALPHA, COEF, FAC, C1, C2, V, V1, V2,
      2
                  TAU, VIN, VOUT, ONE, ZERO, AO, A1
 \boldsymbol{c}
         DIMENSION IBUFR(16)
         COMMON VBLKMMV AA, B, C, R, FREQ, PERM, DERENC, EPSLINK, AM, NOELLS,
                          EINC1(360), VINC1851), ESCAT(360).
      1
      2
                          ECHWPW(360), KO, K2, VOUT(1851), TAUX 1851),
      3
                          EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
 C
         EQUIVALENCE (NCELLS, NZ)
 C
 \epsilon
         DATA PI/3.14159265/
         NX0P=2.*1000
         NY 0P=1.75*1000
 Ċ
         NXSTP=0.8*1000
         NYSTP=0.5*1000
 C
         NXSTPS=9
         NYSTPS=10
         IPEN=1
         WRITE(25,3) IPEN
 €:
          NXEP=NX 0P+NXSTPS*NXSTP
         WRITE(25,1) NXOP, NYOP
         WRITE(25,1) NEEP, NYOP
           WRITE(25,2)
          NYEP=NYOP+NYSTPS*NYSTP
         WRITE(25,1) NXOP, HYOP
         WRITE(25,1) NXOP, NYEP
           WRITE(25,2)
 C
          DO 100 J=1,HXSTPS
            IX=NXOP+J*NXSTP
            IYI=NYOP-50
            1Y2=HY0F+50
           WRITE(25,1) IX, IY1
```

```
WRITE(25,1) 1%,172
           MR1TE(25,2)
100
         CONTINUE
         DO 200 I=1, NYSTPS
           IY=NYOP+I*MYSTP
           IX1=HX0P-50
           102=f00F+50
          WRITE(25,1) 181,19
WRITE(25,1) 182,19
           WF ITE(25,2)
200
        CONTINUE
C
        CALL ECLEL
        CALL LABEL(1)
C
        NPTS=IFIX(180./DGRENC)
Ċ.
        IPEN=3
        WRITE(25,3) IPEN
C
        DO 400 IPHI=1,HPTS
           ID=IFIX((IPHI-1.)*DGRENC/20.*NXSTP+2000.)
           THE IFING (ECHREGIC IPHI) ZWMAX (ZO. 1 *** TP+1750. )
         WRITE(25,1018,1Y
       CONTINUE
400
C
        WRITE(25,2)
       FORMAT: "PA", 15", "I5, "; PD")
       FORMATIC "PU" >
2
       FORMATC "IN; SP", I1)
        END
        END#
```

```
T T=00004 IS ON CROOGES USING 00004 BLKS R=0000
 FTH4,L
 SEMAL BILKINM, (1)
 SUBROUTINE PLDCT
  *******************
 C * THIS SUBROUTINE USES THE MOMENT METHOD TO DETERMINE THE SCATTERED
      FIELD FROM SOME DEFINED DESTACLE
 Č:
 C.
         INTEGER NCELLS, NPTS, PTORS, IPHI, MCELLS
 C
         REAL XNN, YNN, EMAGI, 31, 30, K0, K2, Y0, Y1, EMAGN,
              ECHUPU
 C
         COMPLEX CMM, EINC1, EINC0, EINC2,
                  ESCAT,
                  TAUI, ALMOA, ALPHA, COEF, FAC, C1, C2, V, V1, V2.
      2
                  TAU, VIN, VOUT, ONE, ZERO, DUMMY8, AO, A1
      3
 £.
         DIMENSION IBUFR(16)
 C
         COMMON /BLKMM/ AA.S.C.R.FREQ.PERM.DGRENC.EPSLNR.AN.NCELLS.
                         EINC1(360), VIN(1851), ESCAT(360),
                         ECHMPW(360), KO, K2, VOUT(1951), TAU(1851),
      2
                         EINC2,8CRPEZ(361),DEPRPT(361),A0(1851),A1(1851)
      3
 c
         EQUIVALENCE (NCELLS, NZ)
 C
 C
   •••
 Ċ
         DATA PI/3.14159265/
 C * THE LARGE ARGUEMENT ASYMPTOTIC EXPANSION FOR THE HANKEL FUNCTION
 Ĉ.
      IS USED. SEE RICHMOND -----
 C
   * LOOP NPTS TIMES TO OBTAIN THE SCATTERED FIELD AT EACH DERENC
 C:
 C:
         NPTS=IFIX(360,/DGRENC)
 \boldsymbol{c}
           RN=C-(U/2.)
           THETAN=2.*PI/HCELLS
 C
         DO 20 IPHI=1.MPTS
           PHI=(IPHI-1)*DGRENO*PI/180.
           DUMMY1=(KO*R)-(PIZ4.)
           DUMMY2=-COS( DUMMY1 )
           DUMMY3=-SIHK DUMMY1)
           DUMMY4=SQRT(PI*KO*0.5/R)
   * LOOP NCELLS TIMES
```

DUMMY8=<0..0.)

DO 10 N=1, NCELLS

THETA=(N-1)*THETAM >>NH=RN*COS(THETA) YNN=RN*SIN(THETA)

C

```
DUMMYS=K 0*(NMM*COS(PHI)*YYM*SIN(PHI))
DUMMYT-SIM(DUMMYS)
ARGJ1=K 0*AM
CHL BESEL(1, ARGJ1, BB, Y, BP, YP)
J1=BB
DUMMYS=DUMMYS+KEPSLNR-1.)*VOUT(N)*AM*J1*CMPLX(DUMMYS, DUMMYT)

CONTINUE
C
ESCAT(IPHI)=DUMMY4*CMPLX(DUMMY3, DUMMY2)*DUMMY8

C
RETURN
END
END
END*
```

T=00004 IS ON CR00079 USING 00006 FLKS R=0000

```
FTH4,L
#EMACELKAM, 00
SUBROUTINE TPLZKMM, MNORM, IER)
C
 * From
    "Antenna Theory and Desigh"
      Warren L. Stutzman and Gary A. Thiele
       John Wiley & Sons, New York, 1981
       Appendix 6.7 pp. 579-581
 * PURPOSE
      TO SOLVE A SYSTEM INVOLVING A TCEPLITZ MATRIX. TPLZ REQUIFES
      ONLY IN STORAGE LOCATIONS FOR AN N BY M MATPIX.
C * REMARKS
C A toeplitz matrix has the first row equal to the first column.
  All elements along the main diagonal are equal. Any diagonal
  off the main diagonal will have this same property.
 * DESCRIPTION OF PARAMETERS
ť:
C
   ΝZ
          -ORDER OF MATRIX
C:
   TAU
          -FIRST ROW OR COLUMN OF THE TOEPLITZ MATRIX (VECTOR
           LENGTH NZ)
   AU, AI
          -VECTORS OF LENGTH NZ NEEDED FOR SCRATCH AREA
         FOR THE MATRIX EQUATION (Z)(I)=(V), VIN IS V.
   MIV
C
            AND V MAY BE THOUGHT OF AS GENERALIZED IMPEDANCES,
£:
            CURRENTS, AND VOLTAGES, RESPECTIVELY). V IS A NZ BY
C
            NM MATRIX.
C
          -NUMBER OF COLUMN VECTORS ON THE RIGHT SIDE OF MATRIX
   MM
           EQUATION (Z)(I)=(V) (USUALLY 1),
C
   WHORM -UPON RETURN THIS IS INFINITE MATRIX NORM OF INVERSE.
c
   IER
          -ERROR CODE WHICH IS 0 IF NO TROUBLE.
C
C
       INTEGER NCELLS, NPTS, PTOBS, IPHI, MCELLS
Ċ
       REAL XNN, YNH, EMAGI, J1, J0, K0, K2, Y0, Y1, EMAGN,
            ECHUPU
C
       COMPLEX CMN, EINC1, EINC0, EINC2,
              ESCAT.
              TAU1, ALMDA, ALPHA, CGEF, FAC, C1, C2, V, V1, V2,
    3
              TAU, VIN, VOUT, ONE, ZERO, AO, A1
C
       DIMENSION IBUFR(16)
C
       COMMON /BLKMM/ AA,B,C,R,FREG,PERM,DGPENG,EPSLDR,AN,NCELLS,
                     EINC1(360), VIN(1851), ESCAT(360).
                     ECHWPW(360),K0,K2,VGUT(1851),TAUK1851),
```

The Court of

```
3
                        EINC2, SCRPEZ(361), DBPRPT(361), A0(1851), A1(1851)
ť:
        EQUIVALENCE (NOELLS, NO)
Ċ
        DATA ONEXCIEO, 0E007, ZEROZKOE0, 0E007
        DATA ONNEZIEUZ, ZRROZO.EUZ
C:
C
         WRITE(6,90) NZ, MM
90
        FORMAT(1X, "HZ=",2X,14,5%, "MM=",2X,14,7)
         DO 150 I=1,HZ
Ċ
           WRITE(6,100) TAUKID, VINKID, I
        FORMAT(1X, "TPLZ : TAU=",2X,1E15.8,2X,E15.8,5X, "VIN=",2X,1E15.8.
100
               2X,E15.8,5%,"I=",I4,/>
150
         CONTINUE
        14=142-1
        IER-0
  * HORMALIZE INPUT MATRIX
         TAU1=TAU(1)
        DO 2000 II=1,N
2000
         TAUCITO = TAUCIT+10/TAUT
C * THE FOLLOWING CALCULATES THE ITERATIVE VARIABLES TO OBTAIN
     AUCH) AND ALMDA
C
C * NOTE : VECTOR ACKID HAS I ELEMENTS AND IS STORED AS ACKI, JD,
             J=1, N
C:
         ALMDA=ONE-TAU(1)*TAU(1)
         AGC 10=-TAUC 10
  •:
         I=2
         KK=1-1
         ALPHA=ZERO
        DO 2 M=1,KK
         LL=I-M
        ALPHA=ALPHA+ACKM >*TAUKLL >
  2
         ALPHA=-(ALPHA+TAU(I))
          IF(CARS(ALPHA) .EQ. 0.DQ) GO TO 15
         COEF=ALPHAZALMDA
         ALMDA=ALMDA-COEF*ALPHA
        D0 3 J=1,KK
         L=1-J
   3
        414 d0=400 d0+00EF#40(L)
        DO 7 J=1,KK
        60(d)#A1(d)
         A0(I)=COEF
          IF(I .GE. N) GO TO 5
        I=I+1
         GO TO 1
  * THE FOLLOWING COMPUTES VALUES OF EACH ELEMENT OF THE INVERSE
        NH=(NZ+1)/2
         FAC=ALNDA*TAU1
         XHORN=ZRRO
         MP=MZ+1
        DO 51 I=1,NH
         XHM=ZRRO
```

```
IFKI .NE. 10 GO TO 52
          A1(1)=OHE/FAC
         Xnm=CHB6(H1(10)
        DO 53 U=2,N2
         943\C1-6004<001
  53
        MAKECE YEARSHAK
         GO TO 54
        MHM=ZRRO
  52
          JH= I-1
         01=A(K dH)
         HMPI=NP-1
         C2=A(K)NP(I)
         DO 55 JJ=1,N
           はまがた – せん
           IMPU=NP+U
           は上ニリー1
          A1( 3)=A1( 3L)+(C1*A0( 3L)-C2*A0( IRP3))/FAC
  55
        MNM=CABSCA1CJ>>+XNM
         A1(1)=A0(I~1)/FAC
         XNn=WNM+CABS(A1(1))
  54
           IFKXNM .GT. XNORM) XNORM=XHM
C
C * MOTRIX MULTIPLY
        DO 56 II=1,MM
           ID=(II-1)*NZ
           V≠ZERO
           V1=ZERO
        DO 57 U=1,NZ
          HIDJ=ID+J
           CEGINONIA=8A
           V=V+V2*A1< 3>
          KMP J=NP-J
  57
         V1=V1+V2*A1(KNPJ)
         HIDI=ID+I
          V=CIGIN)TUOW
          WRITE(6,225) VOUT(NIDI), NIDI
225
         FORMAT(1X, "TPLZ : VOUT=",2X,1E15.8,2X,E15.8,5X, "NI=",2X,14,/)
         KIDHPI=ID+HP-I
  56
         VOUT(KIDRPI)=V1
C:
           WRITE(6,250) VOUT(KIDNPI), KIDNPI, VOUT(NIDI), NIDI
         FORMAT(1%,"TPLZ : VOUT=",2%,1E15.8,2%,E15.8,5%,"KI=",2%,I4, 3%,"VOUT=",2%,1E15.8,2%,E15.8,5%,"NI=",2%,I4,/)
250
C
           WRITE(6,251) VOUT(KIENPI), KIENPI
251
         FORMAT(1%, "TPLZ : VOUT=",2%,1615.8,2%,615.8,5%,"KI=",2%,14,/)
C
51
        CONT INUE
C
         DO 650 I=1, NCELLS
C
         WRITE(6,600) VOUT(1),1
600
        FORMATKIX, "TPLZ :: VOUT=",2%,1E15.8,2%,E15.8,5%,"I=",2%,I4,/)
650
        CONT INUE
C
        RETURN
C
  15
         WRITE(6,700)
 700
        FORMAT(1X, "ERROR HAS OCCURRED. MATRIX IS STRONGLY NONSINGULAR")
         IER=1
        RETURN
```

END END\$

EL T=60003 IS ON CR00039 USING 00015 BLKS R=0660

```
FTN4,L
      SUBROUTINE BESEL(N, X, B, Y, BP, YP)
C
      COMPUTE THE BESSEL FUNCTION OF ORDER N, N AN INTEGER NOOR=0
C
      WITH REAL ARGUMENT
C
      ALL EQUATION REFERENCES TO ABRAHOWITZ AND STEGUR
      DIMENSION CO(7),C1(7),D0(7),D1(7),E0(7),E1(7).G0(7),G1(7)
      DATA COZ1.0,-2.2499997,1.2656208.-.3163866,.444479E-1,
     *-.39444E-2,.21E-3/
      DATA C17.5,-.56249985,.21093573,-.3954289E-1,.443319E-2,
     *-.31761E-3,.1109E-4/
      DATA D07.79788456, -.77E-6, -.55274E-2, -.9512E-4, .137237E-2,
     *-.72805E-03,.14476E-03/
      DATA D17.79788456,.156E-5,.1659667E-1,.17105E-3,-.249511E-2.
     *.113653E-02,-.20033E-03/
      DATA EU/-.79539816,-.4166397E-1,-.3954E-4,.262573E-2,-.54125E-3,
     *-.29333E-03,.13558E-03/
      DATA E17-2.35619449,.12499612,.565E-4,-.637879E-2,.74346E-3,
     *.79824E-03,-.29166E-03/
      DATA GOZ.3674669,.6055937,-.7435038,.2530012,-.426121E-01,
     *.427916E-02,-.24846E-03/
      DATA G17-.6366198,.2312091,2.168271,-1.316483,.312395,
     *-.400976E-01,.27873E-02/
      DATA PI/3.1415926/
      IFLG=0
      IF (N.LT.0) IFLG=1
      N=IABS(N)
      IF(ABS(X).LT.1.0E-10)G0 TO 150
      IF(ABS(X),GT.3.0)G0 TO 50
      X3S0=X*X/9.0
      PROD=1.0
      B0=0.0
      Bi = 0, 0
      CUMU=0.0
      CUM1=0.0
      SEE EQUATIONS 9.41 AND 9.44
      DO 5 I=1,7
      Be=B0+C0(I)*PR0D
      B1=B1+C1(I)*PR0D
      CUMO=CUMO+GO(I)*PROD
      CUM1=CUM1+G1(I)*PROD
      PROD=PROD*X3SQ
      CONTINUE
      B1=B1*X
      XC=2.0*SNGL(DLOG(DBLE(0.5*X)))/PI
      Y0=XC*B0+CUM0
      Y1=XC*B1+CUM1/X
      GO TO 100
      EQS 9.4.3 AND 9.4.6
      THROVX=3.0/X
      PROD=1.0
      F 0=0.0
      F1=0.0
      THETA 0=X
      THETA1=X
      DO 55 I=1,7
      F0=F0+D0(I)*PR0D
```

```
F1=F1+D101034PR00
      THETA 0=THETA 0 +E(), I > +PF()
      THETA1=THETA1+E1(I)*PROD
      PROD=PROD*THROVX
55
      CONTINUE
      SQRX=1.0/SNGL(DSQRT(DSLE(X)))
      BO=SORXMFOMSHGL(DOOS(DBLE(THETAO)))
      B1=SORN#F1#SNGL(DCOS(DELE(THETA1)))
      Y0=$0RX*F0*SNGL(DSIN(DBLE(THETAG)))
      Y1=SORX#F1#SNGL(DSIN(DSLE(TRETA1)))
100
      IF(N-10101,105,110
101
      B=80
      BP=-B1
      Y=Y0
      ソア=-71
      GO TO 200
105
      B=81
      BP=B0-B1/X
      Y=Y1
      YP=Y0-Y1/X
      GO TO 200
      FOR RECURRSIVE DIRECTION COMMENTS SEE SECTION 9.12, P385
Ũ
110
      ×H=N
      IFONN.LT.ABSCXDDG0 TO 130
C
      FOR XK N RECUR DOWNWARD
      BLAST=1.0
      BLASTP=0.0
      J=N+10
      DO 115 I=1, J
      \times I = J - I
      BNEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST =BNEXT
      IF(I.NE.10)G0 TO 115
      BLI'=BLASTP
      Z=BHEXT
CONTINUE
115
      IF(ABS(B0).LT.ABS(B1))GO TO 117
      CORR=RO/BLASTP
      GO TO 118
117
      CORR=-B1/BNEXT
      B=BLP*CORR
118
      BNMIN1=Z*CORR
      GO TO 140
      FOR XXM RECUR UPWARD
130
      BLASTP=B0
      BLAST=B1
      DO 135 I=2,N
      \times I = I - 1
      BNEXT=2.0*XI*BLAST/X-BLASTP
      BLASTP=BLAST
      BLAST=BNEXT
135
      CONTINUE
      B=BLAST
      BHMIN1=BLASTP
140
      BP=BNMIN1-XH+B/X
      YEASTP=Y0
      YEAST=Y1
      DO 145 I=2,N
      ×I=1-1
```

YMEXTED, ORNIBYLAST/X-YEASTP YEASTPHYEAST YEHST=YHENT CONTINUE Y=YLAST 145 YP=YEASTP-XM*YZX GO TO 200 150 $R\!=\!0.0$ BP=0.0 Y=0.0 YP=0.0 IF(N-1)155,160,200 155 F:=1 . 0GO TO 200 160 6P≃0.5 P=0.5*X IF (IFLG.E0.0) RETURN 200 RETURN EHD END#

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Electromagnetic Scattering Circular Cylindrical Shell Moment Method Eigenvalue Solution Method	
The problem of scattering by thin cylindrical dielectric shells of large circular cross sections is approached by two methods: (1) an infinite series of eigenfunctions, and (2) the method of moments. Numerical results are presented for shell radii of 0.3h, 3.0h, and 30h, the source being an electric line	

The problem of scattering by thin cylindrical dielectric shells of large circular cross sections is approached by two methods: (1) an infinite series of eigenfunctions, and (2) the method of moments. Numerical results are presented for shell radii of 0.3h, 3.0h, and 30h, the source being an electric line current near but external to the shell. Computer programs are presented which implement these two solutions. When the scattering structure does become large limitations on numerical results are encountered due to computer memory and speed limitations. Other difficulties are also encountered in an analysis of such

